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The Journal of

THE ROYAL AERONAUTICAL SOCIETY

CONTENTS AUGUST 1948

FLIGHT RESEARCH AT HIGH SUBSONIC SPEEDS
H. DAVIES, M.SC., A.F.R.AE.S.

INFLUENCE OF RECENT CIVIL AIRWORTHINESS REQUIREMENTS ON AIRCRAFT DESIGN
W. TYE, O.B.E., B.SC. F.R.AE.S.

MAINTENANCE DESIGN QUESTIONS
LIEUT. (A) (A/E) T. E. G. BOWDEN, R.N., A.F.R.AE.S.

REVIEWS

A GREAT ALL-BRITISH ENTERPRISE

Below : our factories at Leamington

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TWO MILLION HYDRAULIC UNITS SUPPLIED FOR AIRCRAFT

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THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

AUGUST NOTICES 1948

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

AUTUMN LECTURE PROGRAMME

For the first time one of the major lectures of the Society is to be held at a Branch Centre. The first lecture under this new arrangement will be given by Dr. E. W. Still, B.Sc., A.C.G.I., A.F.R.Ae.S., A.F.I.Ae.S. of Rolls-Royce Ltd., at the Birmingham Branch on Wednesday, 6th October 1948.

It is hoped that as many of the members as possible will attend, for if the innovation proves a success the Council hope to arrange a number of the major lectures in the Provinces.

CONTENTS OF THE AUGUST JOURNAL

Flight Research at High Subsonic Speeds, by H. Davies, M.Sc., A.F.R.Ae.S.

Influence of Recent Civil Airworthiness Requirements on Aircraft Design, by W. Tye, O.B.E., B.Sc., F.R.Ae.S.

Maintenance Design Questions, by Lt. (A) (AE) T. E. G. Bowden, R.N., A.F.R.Ae.S.

GARDEN PARTY

In reply to many enquiries, it is greatly regretted that it has not been possible to arrange for a Society's Garden Party this year.

By the kindness of the Society of British Aircraft Constructors, a tent will be reserved for Members of the Society at the S.B.A.C.'s Annual Show at Farnborough on Saturday and Sunday, 11th and 12th September. Admission to the S.B.A.C.'s Display on these two days will be 2/6 for those arriving on foot and £1 for a car, irrespective of the number of people travelling in it. No further charge will be made for admission to those in the car. There will be a charge of £4 for coaches (including admission of passengers).

The Display will be open on Saturday the 11th from 10.30 a.m. and on Sunday, 12th September from 1.0 p.m.

Members are reminded that they should carry their membership cards in order to gain admittance to the Society's tent.

Application for tickets and car labels should be made direct to National Car Parks Ltd., 28 Grosvenor Street, London, W.1, and NOT to the Royal Aeronautical Society. Tickets will also be on sale at the entrance gates.

ANGLO-AMERICAN AERONAUTICAL CONFERENCE 1949

Arrangements are now being made by the Institute of the Aeronautical Sciences and the Society for the Second Anglo-American Aeronautical Conference, which will be held in America in the late spring of 1949. Full details of the programme and arrangements will be published as soon as possible. Members who propose to attend should inform the Secretary.

BIRTHDAY HONOURS

We regret that the following was omitted from the list of Birthday Honours published in July:—

ORDER OF THE BRITISH EMPIRE (Military Division)

Wing Commander A. J. Nicholas (Associate Fellow).

BUSK STUDENTSHIP IN AERONAUTICS

The Busk Studentship in Aeronautics for the year 1948-9 has been awarded to Arthur John Cable, a Student Member of the Society, of the Merchant Venturers' Technical College, Bristol University.

THE ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize was presented on 28th July 1948 to 582494 Ellis, D. —Fitter 11(E)—Sgt./App./Air, the Aircraft Apprentice of the August 1945 Entry who obtained the highest marks in the General Studies Examination.

REES JEFFREYS RESEARCH STUDENTSHIP IN TRANSPORT

Through the generosity of Mr. W. Rees Jeffreys a scholarship worth about £200 a year has been established at the London School of Economics to enable a suitable candidate to devote at least one year to full-time research into the Economics of Transport.

The object of the Founder is to promote research "into the economics and means of transport with a view to securing the balanced development of the various forms of transport and the progressive lowering of charges." Any scheme of research likely to further those ends will receive consideration.

The Studentship is open to University Graduates and to any person who is, or has been, engaged in the administration of transport, the construction of transport facilities (such as roads and bridges) or the manufacture of transport equipment. Although the Studentship will be awarded for one year at a time a holder, or part holder, of the Studentship may apply for a further year's grant.

A condition of the election of a candidate is that he shall register as a full-time Student at the London School of Economics and pay the appropriate fees, which will amount to approximately £20. Also, a candidate must undertake to devote himself *exclusively* to his research.

The first Rees Jeffreys Research Studentship in Transport will be granted for the calendar year 1949 and applications must be received not later than the 31st October 1948. Application Forms and further particulars may be obtained from the Secretary, London School of Economics, Houghton Street, Aldwych, London, W.C.2.

LECTURE PROGRAMME—AUTUMN SESSION 1948

Unless otherwise stated, lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30 p.m.

Thursday, 30th September 1948

Fourth British Commonwealth and Empire Lecture.

Some Economic Factors in Civil Aviation, with Emphasis on Civil Aircraft and their Prospective Trends of Development, by Peter G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.Inst.Mech.E.

Wednesday, 6th October 1948

Some Aspects of Power Plant Development, by Dr. E. W. Still, B.Sc., A.C.G.I., A.F.R.Ae.S., A.M.I.Mech.E.

At the Chamber of Commerce, Birmingham, at 7.30 p.m.

Thursday, 21st October 1948

Cold Weather Operation of Aircraft, by G. W. Wilson, A.F.R.Ae.S., M.I.Ae.S., and Squadron Leader E. P. Bridgland, R.C.A.F., B.Sc., A.F.R.Ae.S., A.F.I.Ae.S.

Thursday, 28th October 1948

Aircraft Engineering and Production, by a Member of the Staff of Handley Page Ltd.

Saturday, 20th November 1948

FULL DAY DISCUSSION ON HELICOPTERS
(A Joint Meeting with the Helicopter Association)

Morning Session

11 a.m. to 1 p.m.—GENERAL PROBLEMS OF THE HELICOPTER FOR CIVIL USE.

11 a.m.—The Operational Point of View, by W/Cdr. R. A. C. Brie, A.F.R.Ae.S., A.F.I.Ae.S.
11.30 a.m.—The Technical Point of View, by Capt. R. N. Liptrot.
12 noon.—Discussion.
1 p.m. to 2.30 p.m.—Luncheon Interval (Members should make their own arrangements).

Afternoon Session

2.30 p.m. to 4.30 p.m.—THE CONSTRUCTORS' APPROACH TO THE PROBLEMS.
2.30 p.m.—The Fairey "Gyrodyne," by Dr. J. A. J. Bennett, D.Sc., M.A., D.I.C., F.R.Ae.S., F.Inst.P.
3.0 p.m.—The "Bristol 171" Helicopter, by R. Hafner.
3.30 p.m.—The Cierva "Air Horse," by J. S. Shapiro, Dipl.Ing., A.F.R.Ae.S.
4.0 p.m.—Discussion.
4.30 p.m. to 5 p.m.—Tea Interval. (Tea will be provided at the Lecture Hall.)

Evening Session

5 p.m. to 6.30 p.m.—General Discussion and summing up by the Lecturers and the Chairman.

Thursday, 25th November 1948
Development of the Armstrong Siddeley Mamba Engine, by W. H. Lindsey, M.A., A.F.R.Ae.S.

Thursday, 2nd December 1948
Problems in the Development of a New Aeroplane, by G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S.

Thursday, 16th December 1948
Present Thoughts on the Use of Power Flying Controls in Aircraft, by D. J. Lyons.

BRANCH NOTICES

BROUGH BRANCH

Saturday, 21st August 1948—Air Display at Brough Aerodrome.

GLASGOW BRANCH

Thursday, 26th August 1948—" Lecturettes." At The Grand Hotel, Charing Cross, Glasgow.
Tuesday, 28th September 1948—A Film Evening, at 7.30 p.m., at Prestwick Airport.
Thursday, 28th October 1948—Lecture by a Branch Member, at 7.30 p.m., at The Grand Hotel, Charing Cross, Glasgow.
Tuesday, 30th November 1948—" Lecturettes," at 7.30 p.m., at Prestwick Airport.
Thursday, 23rd December 1948—Annual General Meeting, at The Grand Hotel, Charing Cross, Glasgow.

HATFIELD BRANCH

Wednesday, 13th October 1948—Aircraft Photography, by John Yoxall.
Wednesday, 17th November 1948—Design Problems of Large Flying Boats, by H. Knowler, F.R.Ae.S.
Wednesday, 12th January 1949—Blind Landing Technique, by J. W. F. Mercer, B.Sc., A.C.G.I.
Wednesday, 16th February 1949—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.
Wednesday, 16th March 1949—Annual General Meeting.
All Meetings will be held at 6.15 p.m. in the de Havilland Senior Staff Mess.

PORTSMOUTH BRANCH

Friday, 24th September 1948—Flight Refuelling, by C. H. Latimer-Needham, F.R.Ae.S., at 7 p.m., in the Central Library (Guildhall Square), Portsmouth.

GRADUATES' AND STUDENTS' SECTION

Saturday, 14th August 1948—Visit to the National Physical Laboratory, Teddington, at 10 a.m.

Saturday, 28th August 1948—Visit to the factory of Vickers-Armstrongs Ltd. (Aircraft Section), at Weybridge, at 10 a.m.

Members wishing to take part in these visits should write to the Assistant Hon. Secretary, D. A. Thurgood, 81 Bourne Avenue, Hayes, Middlesex, before 1st August. The numbers will be strictly limited, and early application is advisable.

Wednesday, 8th September 1948—Visit to the Ford Motor Company, Dagenham, Essex, at 2 p.m.

Saturday, 25th September 1948—Visit to Northolt Airport, Ruislip, Middlesex, at 10.30 a.m.

Members of the Section wishing to take part in these visits should write to the Hon. Secretary, Michael C. Campion, 6a Mildenhall Road, Clapton, E.5, not later than 1st September 1948.

JOURNAL BINDING

Because of increased costs, the prices of binding of Journals will be as follows:—

1947 Volume 15/-.
Previous Volumes 17/-.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the* **15*th of the month*** in order to be effective for the Journal for the following month.

NEW MEMBERS

Associate Fellows

James Douglas Anderson (from Graduate), Ralph Leonard Apsden, Harold William Russell Banting (from Associate), William Gall Driver, Giuseppe Gabrielli, James William Spracking, Roland Graham L'Estrange Wallace (from Graduate), James Benjamin Yates (from Associate).

Associates

Sunder Lal Atal, Keith Berkley Crosby, Nils Jacob Gille, William Wightman McCombe.

Graduates

John Frederick Clarke (from Student), Reginald George Evans (from Student), Geoffrey Lindley Harrison, James Dougal Harris (from Student), William Risbee Heald, William George Hearle, Antoni Lewandowski, Reginald Arthur Langley, Robert Rose, Frank Melvin Stansfield (from Student), Brian Worsley Bolton Shaw, Prabandam Srinivasan, Alan John Wangford, Peter William Wreford.

Students

Khwaja Mohiuddin Ahmed, Reginald Albert Lloyd Arkell, Ian Campbell Carrott, Alan Arthur Hawkins, Charles David Hollis, Bryan Rex Noton, Robert Charles Pennicott, Raymond Victor Sabin, John Derek Teare.

Companions

William Tait Gill, Sydney Lacy Hebard, Alfredo Ramon Junque-Gasso, Ernest George Cuthbert Leathem, Peter Sweetman, Peter George Tranter.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks back numbers of the Journal from D. S. Bliss, Esq., Student.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.349—Theory of Limit Design. J. A. van den Broeck. John Wiley. 1948.
BB.b.135—Aircraft Structural Analysis. Mangurian and Johnston. Prentice Hall, New York. 1948.
BB.f.69—Scientific Instruments II. H. J. Cooper. Hutchinson. 1948.
E.b.128—Flight Engineering and Cruise Control. Harris G. Moe. John Wiley. 1947.
*E.b.129—Proceedings of the Society for Experimental Stress Analysis. Vol. V, No. I. Addison Wesley Press, U.S.A. 1947.
EE.h.35—Jet Propulsion in Commercial Air Transport. R. E. Hage. Princeton University Press. 1948.
G.a.81—The Failure of Metals by Fatigue. H. J. Gough (Editor). Melbourne University Press. 1947.
G.e.A.118—Pressure Die Casting in Light and Heavy Non-ferrous Alloys. Birmal. Birmingham Aluminium Casting Co. Ltd.
I.e.35—Tables of Physical and Chemical Constants. Kaye and Laby. 10th Edition. Longmans. 1948.
J.g.214—Observing the Weather. B. C. Haynes. John Wiley. 1947.
L.d.123—*Notices to Airmen. Nos.* 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 247, 248, 249, 250.
L.k.67—Advanced Industrial First Aid. 1947. R. A. Trevethick. H. Garnett & Co. 1947.
Q.a.188—Bibliography of Books and Articles on Closed Sequence Control. Ministry of Supply.
S.d.98—Air Power can Disarm. J. M. Spaight. Pitman. 1948.

N.A.C.A. Technical Memoranda

1125—*The influence of the diameter ratio on the characteristics diagram of the axial compressor. B. Eckert, F. Pfluger and F. Weinig.*
1176—*Test report on three- and six-component measurements on a series of tapered wings of small aspect ratio. Lange/Wacke.*
1191—*Venturi tubes with varying mass flow. B. Regenscheft.*

N.A.C.A. Technical Notes

1096—*On supersonic and partially supersonic flows. Stefan Bergman.*
1123—*Lateral-control characteristics of various spoiler arrangements as measured in flight. J. R. Spahr.*
1146—*Tests to determine the effects of slipstream rotation on the lateral stability characteristics of a single-engine low-wing airplane model. P. E. Purser and M. F. Spear.*
1152—*Flight investigation of the effect of a local change of wing contour on chordwise pressure distribution at high speeds. R. E. Adams and N. S. Silsby.*
1155—*A preliminary study of a propeller powered by gas jets issuing from the blade tips. J. C. Sanders and N. D. Sanders.*
1156—*Column and plate compressive strengths of aircraft structural materials. Extruded* 0-1*HTA magnesium alloy. G. J. Heimerl and D. E. Niles.*
1157—*Compressive strength of* 24*S-T aluminium-alloy flat panels with longitudinal formed hat-section stiffeners. E. H. Schuette, Saul Barab and H. L. McCracken.*
1158—*Flutter and oscillating air-force calculations for an airfoil in a two-dimensional supersonic flow. I. E. Garrick and S. I. Rubinov.*

1162—*Effect of brake forming in various tempers on the strength of alclad 75S-T aluminium-alloy sheet. W. Woods and G. J. Heimerl.*

1164—*The synthesis and purification of aromatic hydrocarbons V-I-Ethyl-3-Methylbenzene. E. R. Ebersole.*

1165—*Tensile properties of a sillimanite refractory at elevated temperatures. A. E. Kunen, F. J. Hartwig and J. R. Bressman.*

1167—*Pressure distributions and force tests of an NACA 65-210 airfoil section with a 50-per cent.-chord flap. M. M. Klein.*

1169—*The effect of geometric dihedral on the aerodynamic characteristics of a 40 degree swept-back wing of aspect ratio 3. B. Maggin and R. E. Shanks.*

1170—*On subsonic compressible flows by a method of correspondence. I—Methods for obtaining subsonic circulatory compressible flows about two-dimensional bodies. Abe Gelhardt.*

1179—*Notes on the theoretical characteristics of two-dimensional supersonic airfoils. H. Reese Ivey.*

1180—*Analysis of jet-propulsion engine combustion-chamber pressure losses. I. I. Pinkel and H. Shames.*

1182—*A collection of the collapsed results of general tank tests of miscellaneous flying-boat hull models. F. W. S. Locke, Jr.*

1183—*Theoretical lift and drag of thin triangular wings at supersonic speeds. C. E. Brown.*

1184—*Theory of ground vibrations of a two-blade helicopter rotor on anistropic flexible supports. R. P. Coleman and A. M. Feingold.*

1186—*Review of an investigation of ceramic coatings for metallic turbine parts and other high-temperature applications. W. N. Harrison, D. G. Moore and J. C. Richmond.*

1191—*Two-dimensional wind-tunnel investigation of four types of high-lift flap on an NACA 65-210 airfoil section. J. F. Cahill.*

1192—*Charts showing relations among primary aerodynamic variables for helicopter performance estimation. H. W. Talkin.*

1404—*Collection of test data for lateral control with full-span flaps. J. Fischel and M. F. Ivey.*

1436—*Stress in and general instability of monocoque cylinders with cutouts. VI—Calculation of the buckling load of cylinders with side cutout subjected to pure bending. N. J. Hoff, B. Klein and B. A. Boley.*

1443—*Shear leg in a plywood sheet-stringer combination used for the chord member of a box beam. Palamede Borsari and Ai-ting Yu.*

1462—*Bending of rectangular plates with large deflections. Chi-Teh Wang.*

1464—*Effects of surface finish, of certain defects, and of repair of defects by welding on fatigue strength of 355-T6 sand-castings and effects of prior fatigue stressing on tensile properties. F. M. Howell, G. W. Stickley and J. O. Lynt.*

1470—*The effect of fuel composition, compression pressure, and fuel-air ratio on the compression-ignition characteristics of several fuels. W. A. Leary, E. S. Taylor, C. F. Taylor and J. Jovellanos.*

1498—*Effect of local boiling and air entrainment on temperatures of liquid-cooled cylinders. A. P. Colburn, C. Gazley, Jr., E. M. Schoenborn and S. C. Sutton.*

1512—*Stress-strain and elongation graphs for alclad aluminium-alloy 24S-T sheet. J. A. Miller.*

1513—*Stress-strain and elongation graphs for alclad aluminium-alloy 24S-T81 sheet. J. A. Miller.*

1521—*Full-scale investigation of the blade motion of the PV-2 helicopter rotor. E. Migotsky.*

1525—*Stress and distortion measurements in a 45 degree swept box beam subjected to bending and to torsion. G. Zender and C. Libove.*

1526—*A general small deflection theory for flat sandwich plates. C. Libove and S. B. Batdorf.*

1545—*Wind-tunnel investigation of seven thin NACA airfoil sections to determine optimum double-slotted-flap configurations. J. F. Cahill and S. F. Raciez.*

1553—*Compressive strength of 24S-T aluminium-alloy flat panels with longitudinal formed hat-section stiffeners having four ratios of stiffener thickness to skin thickness. A. W. Hickman and Norris F. Dow.*

1555—*The theoretical lift of flat swept-back wings at supersonic speeds. Doris Cohen.*

1556—*A unified theory of plastic buckling of columns and plates. E. Z. Stowell.*

1557—*Compressive buckling of simply supported plates with transverse stiffeners. B. Budiansky and P. Seide.*

1558—*Notes on the langrangian multiplier method in elastic-stability analysis B. Budiansky, Pai C. Hu and R. W. Connor.*

1559—*Buckling stresses of clamped rectangular flat plates in shear. B. Budiansky and R. W. Connor.*

1563—*Effect of partial wing lift in seaplane landing impact. S. U. Benscoter.*

1564—*Methods of constructing charts for adjusting test results for the compressive strength of plates for differences in material properties. G. J. Heimerl.*

1565—*Buckling in shear of continuous flat plates. B. Budiansky, R. W. Connor and Manuel Stein.*

1566—*Damping in pitch and roll of triangular wings at supersonic speeds. C. E. Brown and Mac C. Adams.*

1567—*Simulated-altitude investigations of performance of tubular aircraft oil coolers. S. V. Manson.*

1568—*Design and performance of family of diffusing scrolls with mixed flow impeller and vaneless diffuser. W. B. Brown and G. R. Redshaw.*

1570—*Hydrodynamic qualities of a hypothetical flying boat with a low-drag hull having a length-beam ratio of* 15. *W. A. Carter and M. I. Haar.*

1572—*Stability derivatives of triangular wings at supersonic speeds. H. S. Ribner and F. S. Malvestuto, Jr.*

1573—*Flight measurements of the flying qualities of five light airplanes. P. A. Hunter.*

1577—*Note on similarity conditions for flows with heat transfer. A. E. von Doenhoff.*

1578—*Friction of solid films on steel at high sliding velocities. R. L. Johnson, D. Godfrey and E. E. Bisson.*

1579—*Investigation in the Langley* 19-*foot pressure tunnel of two wings of NACA* 65-210 *and* 64-210 *airfoil section with various type flaps. J. C. Sivells and S. H. Spooner.*

1581—*Approximate relations and charts for low-speed stability derivatives of swept-wings. T. A. Toll and M. J. Queijo.*

1582—*Wind-tunnel investigation of effects of forward movement of transition on section characteristics of a low-drag airfoil with a* 0.24 *chord sealed plain aileron. S. F. Raciez and J. F. Cahill.*

1584—*An evaluation of some approximate methods of computing landing stresses in aircraft. E. Z. Stowell, J. C. Houbolt and S. B. Batdorf.*

1585—*Theoretical distribution of lift on thin wings at supersonic speeds. (An extension.) J. C. Evvard.*

1586—*Investigation of effectiveness of air-heating a hollow steel propeller for protection against icing I—Unpartitioned blades. D. R. Mulholland and P. J. Perkins.*

1587—*Investigation of effectiveness of air-heating a hollow steel propeller for protection against icing. II—*50 *per cent. partitioned blades. P. J. Perkins and D. R. Mulholland.*

1588—*Investigation of effectiveness of air-heating a hollow steel propeller for protection against icing. III—*25 *per cent. partitioned blades. D. R. Mulholland and P. J. Perkins.*

Index of N.A.C.A. Technical Publications 1915-1947

The following reports have also been received:—

British Intelligence Objectives Sub-Committee
B.I.O.S. Final Reports Nos. 1612 *and* 1661.
B.I.O.S. Miscellaneous Report No. 72.

Publications Scientifiques et Techniques du Ministere de l'Air
Report Nos. 214 *and* 215.
Technical Notes Nos. 27 *and* 28.

Nationaal Luchtvaartlaboratorium, Amsterdam
*Report No. S.*311.

Flytekniska Forsolstalten Ffa
Meddelande No. 24.

J. LAURENCE PRITCHARD,
Secretary.

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ACTIVITIES OF THE GRADUATES' AND STUDENTS' SECTION

August 1948

Visits have been arranged to the Ford Motor Works, Dagenham, Essex, on Wednesday 8th September and to Northolt Airport on Saturday 25th September 1948.

The visit arranged for Saturday 10th July to the works of D. Napier and Son Ltd., Acton, had to be cancelled because of the small number of members who applied to take part. A visit was made to the R.A.E. on Tuesday 20th July.

LECTURE

The last lecture of the 1947-48 Session was held in the Council Room at 4 Hamilton Place, on Tuesday 11th May. The Section Chairman, Mr. J. W. F. Housego was in the Chair. A summary is given below of the paper, "Light Aircraft and the Future of Private Flying," which was read by Mr. P. G. Masefield, F.R.Ae.S., Director-General of Long-term Planning and Projects, Ministry of Civil Aviation, and a past Chairman of the Section.

Introduction

Small boat sailing had been a great asset to Britain as a seafaring nation and light aeroplane flying bore a similar relationship to Aviation. A healthy Light Aircraft Movement provided a firm basis for export trade, as had been proved during the inter-war years, when a large proportion of the civil aircraft built in Great Britain had been light types, many of them for export. It had enabled a number of manufacturers to keep going at a time when there was little demand for large or military aircraft. In the future, it would, he hoped, provide a necessary incentive for young designers and technicians. Enthusiasm for private flying had given the country the services of many outstanding people, both during peace and war. The Royal Navy had saved considerable time and expense by absorbing 510 amateur trained pilots, and the Air Transport Auxiliary had been formed initially of amateur pilots. Light aeroplane flying was capable of providing the necessary air faring outlook which was required for Britain to be a leading air power.

Historical Background

Before 1914, virtually all flying had been amateur and all aircraft light. During the Great War, although aircraft were developed for military purposes, they remained light, by modern standards. There was little private flying from 1918 until 1923, when the Duke of Sutherland initiated a competition for light aircraft. This was followed by a similar competition in 1924, held by the Air Ministry. The aircraft resulting from these were too light and slow for serious flying, and the competitions did not achieve their real object. In 1925, de Havilland built the first Moth, the D.H.60, Cirrus Moth, which made possible the birth of a real Light Aircraft Movement. State assistance was obtained to enable the formation of six flying clubs, equipped with Moths. The movement gradually expanded, until in 1938 there were 62 clubs, with 400 aircraft and about 4,000 active flying members. In that year, the Civil Air Guard scheme was started and enabled members to fly at the cost, to them, of half-a-crown per hour. After a year of existence, during which 10,000 pilots were under training, at a cost to the country of £250,000, war was declared, and private flying ceased.

The Present

Although there were about 50 clubs in existence at present, there were no subsidies, and as it cost about £4 per hour, there were few people able to indulge in private flying. In 1947, Lord Nathan, then Minister of Civil Aviation, had appointed a Committee, under the chairmanship of Mr. Whitney Straight, to investigate the state of the light flying movement. This Committee had reported that Government subsidies were essential to the survival of private flying, and recommended a developing scheme to reduce the cost of flying to the individual to not more than £1 per hour, for a maximum of 50 hours per person per year. With 100 clubs and 600 aircraft, the scheme would cost, in its third year, £900,000 to train 10,000 pilots.

About the same time, Mr. Masefield had inaugurated the Informal Light Aircraft Committee, whose conclusions had been embodied in the report of the Whitney

Straight Committee, and endorsed by that Committee. The I.L.A.C. had recommended that the Government should underwrite the development and production of a two-seater light trainer, of which 1,000 should be ordered by the Government, which would, in theory, recover most of its initial outlay by selling the aircraft. Unfortunately, these reports and the Economic Crisis coincided.

The costs of amateur flying were divisible into two groups, namely, the fixed annual costs, which were independent of the number of hours flown, and the hourly direct costs, which varied with the number of hours flown. For a club with three aircraft, the fixed annual cost including salaries and maintenance was about £5,000, while the hourly cost was about 15 shillings per hour. If each aircraft was operated for 100 hours per year, the total flying cost was over £17 per hour. This was reduced considerably as the number of hours flown increased, becoming £4 per flying hour with a utilisation of 500 hours per aircraft per year. For the private owner, the direct cost was increased by maintenance fees per hour, and although the annual cost was reduced, the total cost amounted to about £700 per annum for 100 flying hours, or £7 per hour.

These costs were far too high to be afforded generally. An analysis of the fixed annual cost showed salaries of the flying instructors to be the largest item (32 per cent.), which could not be reduced. Maintenance costs, which could be reduced only by better detailed design for greater reliability, came to 24 per cent. and depreciation amounted to 12 per cent. of the total, although this was capable of reduction if all-metal aircraft of greater durability could be produced in quantity. Club overhead expenses accounted for some 10 per cent. and insurance for 9 per cent.; this was again high, and would probably drop if greater safety were achieved. The remaining 13 per cent. was made up of C. of A. fees, rent, rates, hangarage and personnel insurance.

Of the 15 shillings per hour variable cost, fuel and oil totalled 53 per cent., airframe maintenance formed 17 per cent., and engine overhauls 20 per cent. These latter would be less if better detail design and engine reliability were achieved.

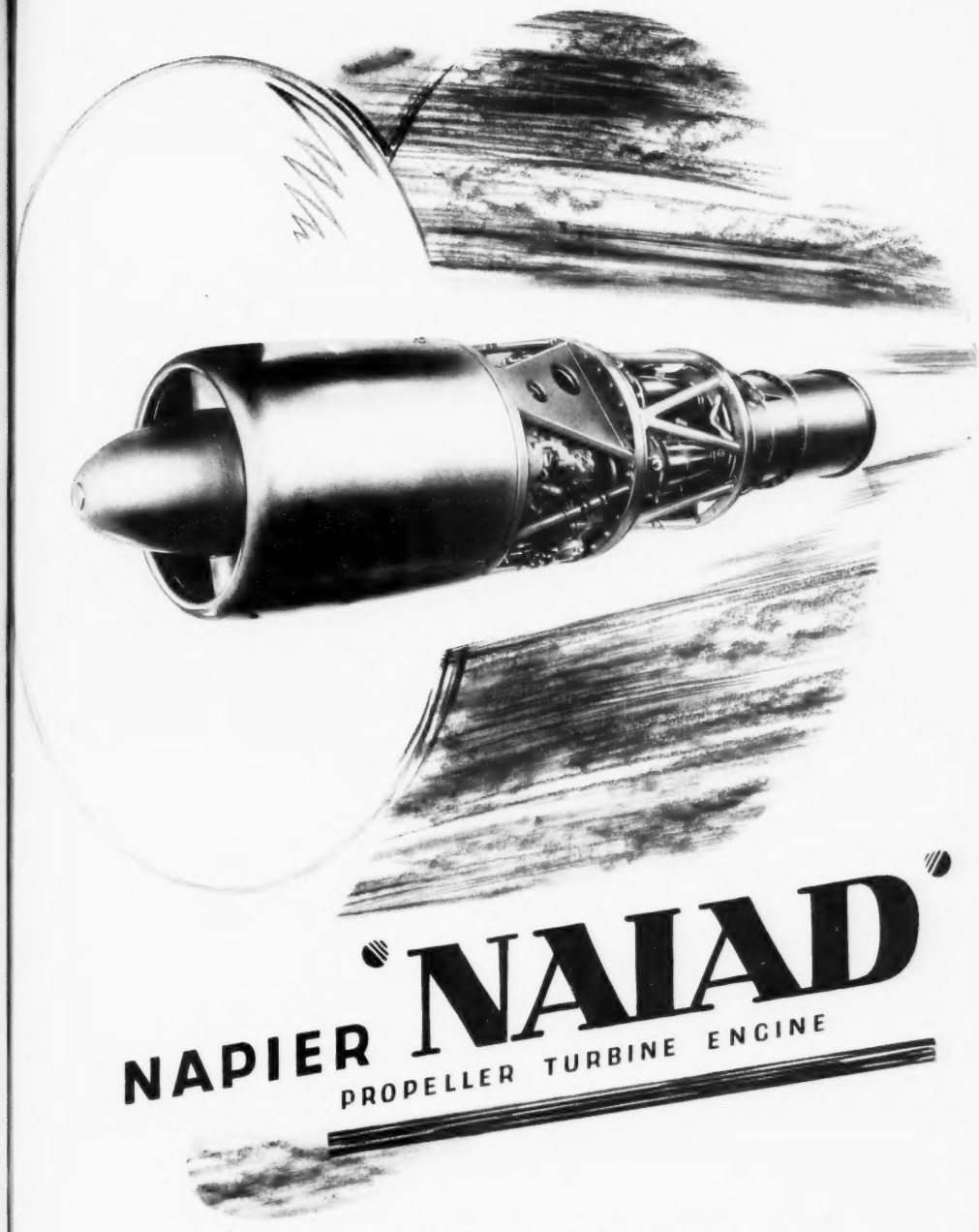
Other ways of reducing costs were to increase the utilisation of the aircraft, which brought the cost down from over £17 per hour at 100 hours per year, to £3 per hour at the maximum practicable utilisation of 750 hours, for a club operating three aircraft. If the number of aircraft were doubled, the minimum cost was reduced to £2 10s., but a further increase in the number of aircraft had little effect. The conclusion reached from the above analysis was that for minimum cost a club should operate not less than six aircraft for at least 750 hours per year each, and that the aircraft should be designed to have good reliability, simple maintenance characteristics, and low fuel consumption. This would keep the hourly flying cost in the region of £2 10s. The club might augment its income by social events, catering and flying displays, and if £3,000 could be raised in this way per year, the net flying costs could be brought down to some £1 15s. per hour, which was approaching the target figure of £1 per hour.

The majority of the aircraft types which had made flying so popular between the wars were no longer available, and of the types now being built, few were suitable for training and club use. The I.L.A.C. had, in its report, described a type which after long discussion appeared the best compromise for club use; it would probably be a two-seater, all-metal monoplane with tricycle undercarriage, enclosed cabin, and with an engine capable of giving five hours' duration at a cruising speed of 110 m.p.h., and a take-off run of not more than 400 yards. It should be of robust construction, designed for ease of maintenance, and should not have hydraulic, pneumatic, or oleo-pneumatic systems.

Other possible solutions were the helicopter, which was at present rather complex and expensive, and the "Roadable." The Consolidated Vultee Convair Roadable "Convaircar" consisted of a small car which could be fitted with a detachable wing, carrying an engine and airscrew and a tail boom with the empennage. A hire system for the wings might be developed, so that the owner of the car part could hire the wing unit when required. This method, if successful, would cause a major reduction in the costs of flying, and might solve the problem of cheap flying.

CONCLUSIONS.

The Light Aeroplane Movement was, at the moment, in a precarious position. Costs were about £4 per hour, and even so, most of the clubs were on the verge of insolvency. Provided that some State aid was eventually forthcoming, and if the demand for a really suitable aircraft could be met (by a really brilliant design), then with both export and home markets, aircraft could be produced more cheaply, leading to light flying within the reach of a large number of people.



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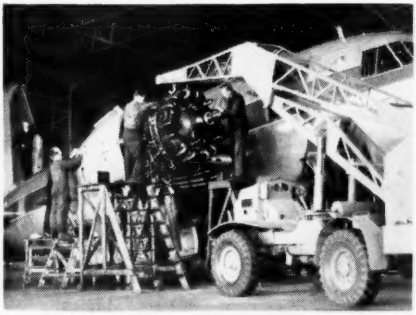

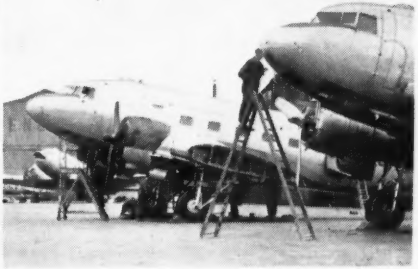

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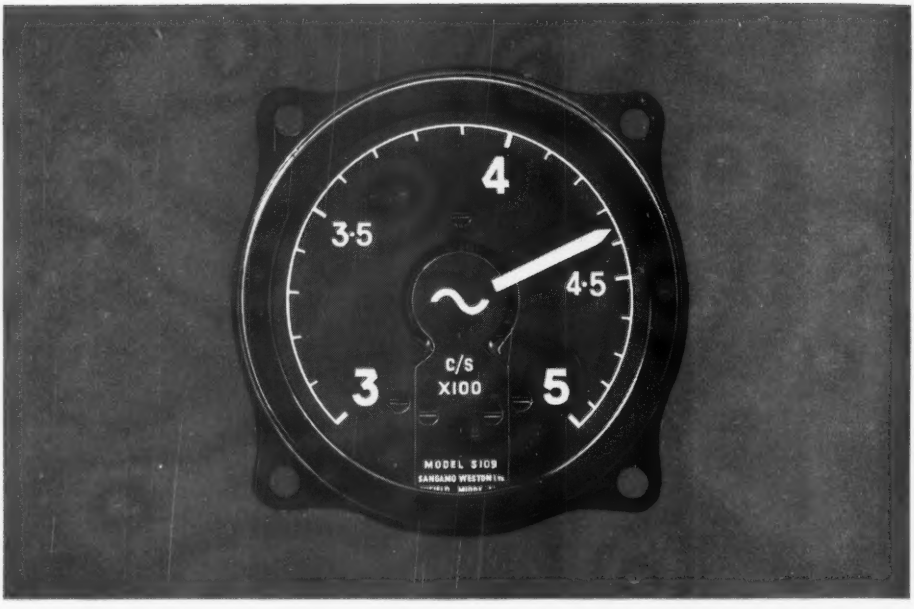

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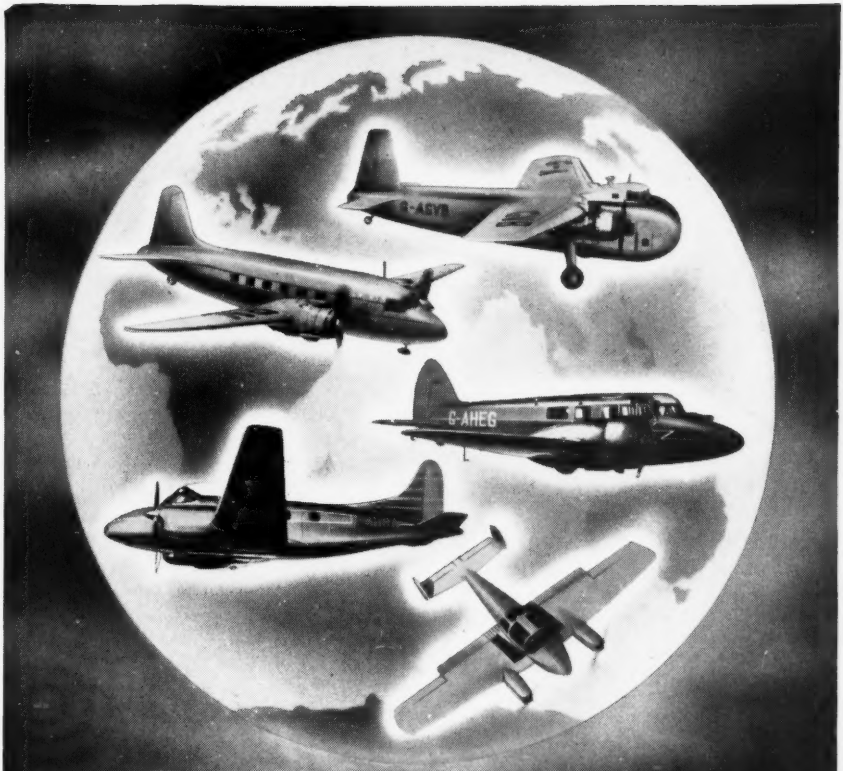

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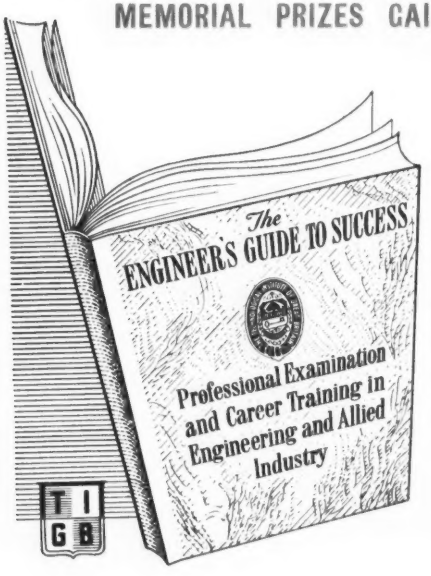

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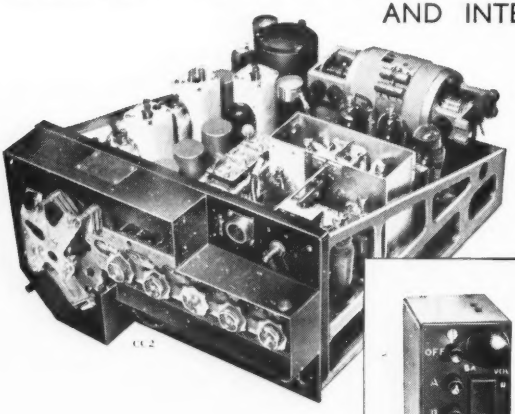

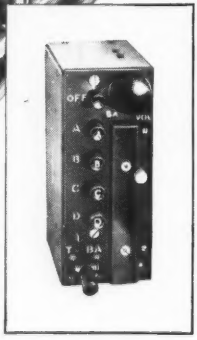

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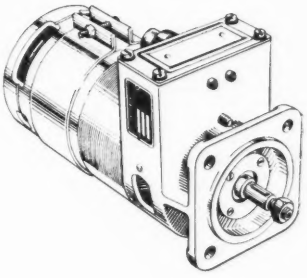

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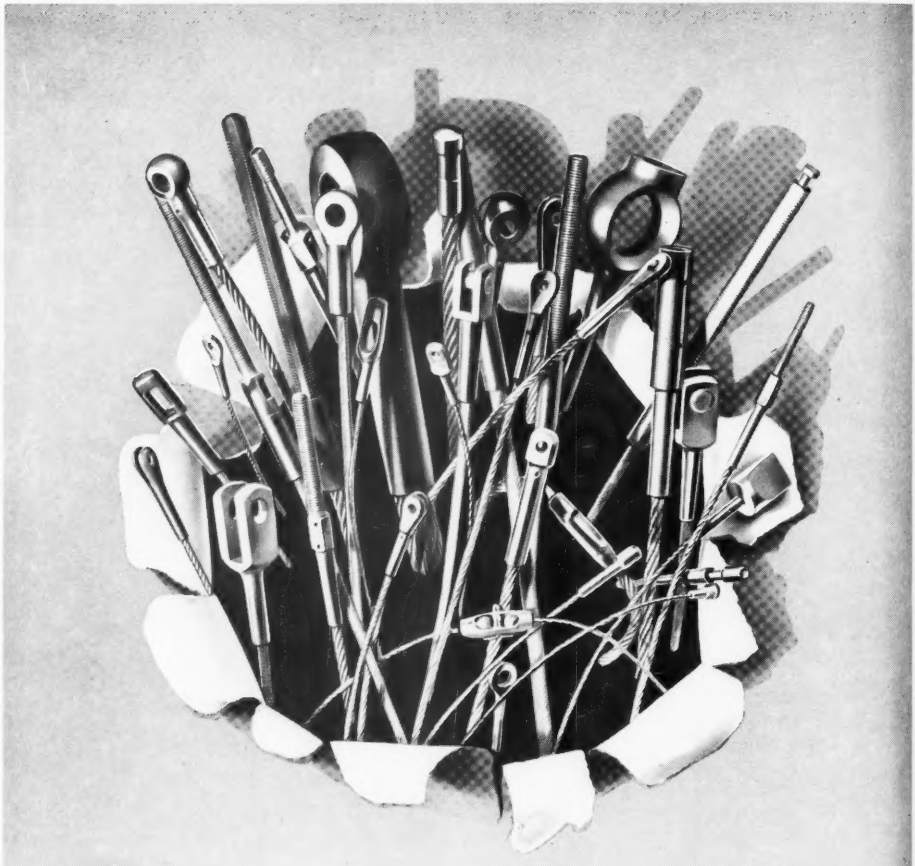

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FLIGHT RESEARCH AT HIGH SUBSONIC SPEEDS

by

H. DAVIES, M.Sc., A.F.R.Ae.S.

1. INTRODUCTION.

Until about ten years ago the highest speeds achieved by aircraft, even in dives, rarely exceeded half the speed of sound. Under these conditions the air round the aircraft behaved very much as if it were incompressible, and the forces acting on the aircraft could be derived on the basis of laws governing the aerodynamics of incompressible fluids.

During the 1939-45 War great advances were made in the performance of aircraft and eventually speeds of over three-quarters of the speed of sound were being reached, even in level flight. At these speeds the air no longer behaves as an incompressible fluid; the aerodynamic laws involved become much more complicated and the aircraft designer is faced with a mass of new problems, involving many strange and unexpected effects.

The purpose of this lecture is to discuss the contribution which research in flight can make towards the elucidation of these problems, with special reference to work done at the Royal Aircraft Establishment during the past few years.

2. OBJECTIVES OF HIGH SPEED FLIGHT RESEARCH.

It is important at the outset to recognise clearly the limitations to which research in flight must necessarily be subject. It is obviously impossible, for example, to make in flight the comprehensive systematic investigation which is possible in a wind tunnel. The difficulties of making rapid modifications and of measuring directly the forces and moments on the aircraft, which have always existed in flight work, are accentuated in high speed research by the necessity of flying under conditions when violent, and often unpredictable, aerodynamic changes are taking place.

The need to obtain detailed full-scale information with which to check the results of model tests and to assist in the interpretation of these tests, is greater than ever, since the Reynolds Numbers attainable in model work are still low (see Fig. 1) and uncertainties in tunnel corrections have become substantially increased at high Mach numbers.

It is suggested therefore that the main objectives of high speed research should be subdivided as follows:—

(1) Investigations of the interpretation and applicability to full-scale conditions of wind tunnel and other model testing, since these must remain the main sources of fundamental systematic data. The importance of this aspect of the work cannot be over-emphasised.

(2) Work on problems not easily amenable to model or theoretical investigation, such as aeroelastic distortion, or on effects for which model tests have been found to be unreliable.

With these objectives in mind, I shall discuss first the methods and technique which have been developed in high speed flight testing during the past few years, and then the measurement and interpretation of compressibility effects on drag, lift, stability, control and other miscellaneous effects. Finally, I shall discuss briefly the probable trends of future high speed research in flight.

3. METHODS AND TECHNIQUE.

The investigation of compressibility effects in flight involves three important factors affecting the methods and technique employed, which are not present in flight at lower speeds. They are:—

(1) The variations in aerodynamic charac-

The 748th Lecture read before the Society—on 18th March 1948 at the Institution of Civil Engineers, Great George Street, S.W.1. In the Chair, the President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S.

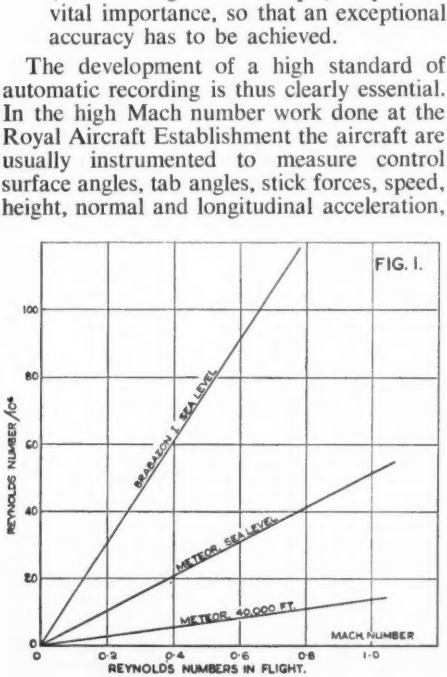
Mr. Davies is Principal Scientific Officer responsible for High Speed Flight Research at the Royal Aircraft Establishment, Farnborough.

teristics which occur at high Mach numbers are often severe and unpredictable, and may have catastrophic effects on the behaviour of the aircraft so that a high standard of piloting skill is essential.

(2) The speeds needed are often higher than can be reached in level flight, necessitating the development of a special dive technique.

(3) Because of the high speeds, very small changes in the quantity being measured (elevator angle for example) may be of vital importance, so that an exceptional accuracy has to be achieved.

The development of a high standard of automatic recording is thus clearly essential. In the high Mach number work done at the Royal Aircraft Establishment the aircraft are usually instrumented to measure control surface angles, tab angles, stick forces, speed, height, normal and longitudinal acceleration,



TUNNEL	METHOD OF TEST	M	R
R.A.E. HIGH SPEED TUNNEL	PARTIAL MODEL	0·8	3×10^6
" " " "	COMPLETE MODEL	0·8	$1·5 \times 10^6$
" " " "	COMPLETE MODEL	0·9	$0·5 \times 10^6$
LANGLEY 16 FT TUNNEL	PARTIAL MODEL	0·6	10×10^6
—	PILOTLESS FLYING MODELS	—	$3·8 \times 10^6$
	MODELS MOUNTED ON AIRCRAFT	—	1×10^6

REYNOLD'S NUMBERS OBTAINED IN TYPICAL MODEL TESTS.

Fig. 1.
Comparison of Reynolds numbers in flight and model tests.

and sometimes incidence and angle of yaw. These instruments may be photographed with an F.24 camera, fitted with a T.35 control so that photographs can be taken automatically at regular intervals; or, if space is restricted, a 35 mm. Robot camera can be used. In cases where rapid fluctuations or oscillations are taking place, a ciné camera may be necessary. More recently, a continuous trace recorder has been developed capable of providing a continuous recording of control angles and accelerations. This will be referred to in more detail later.

The instruments measuring elevator, rudder, aileron and tab angles are connected to desynn transmitters adapted to enable small changes of one or two degrees to be measured accurately. The control surface movement is transmitted to the desynn through a cam designed so that the full range of desynn movement corresponds to a small movement of the control, without restricting the movement of the control itself.

In the early high Mach number work at the R.A.E. normal acceleration was measured with a standard Kollsman type accelerometer. Later, when it became necessary to record fairly rapid variations in acceleration and to obtain accurate measurements of longitudinal acceleration, an accelerometer with adjustable damping and variable natural frequency was improvised and has proved very successful. The instrument is shown in Fig. 2. It consists simply of a weight moving on rotating rollers and constrained by a spring. The weight is made in two halves, with a felt pad between the two halves and the rollers. The damping is adjusted by altering the pressure between the two halves of the weight and the rollers, by means of the screws shown. The natural frequency and the sensitivity can be altered simply by changing the spring. The rollers are driven by a 24 volt D.C. electric motor. The movement of the weight is transmitted through a microdesynn to a recorder in the automatic observer. The application of this instrument to the measurement of drag in the dive will be discussed in detail in section 4.

Incidence and, when required, angles of yaw are usually measured by means of a vane mounted on an arm about 70 per cent. of the chord ahead of the leading edge of the wing. The angle of the vane to a fixed datum is measured by means of a microdesynn transmitter mounted alongside the vane and connected to a desynn receiver in the auto-

matic observer. The accuracy obtained with this instrument (about $\pm\frac{1}{2}^\circ$) is not entirely satisfactory, but it is quite good enough in correcting drag measurements by the longitudinal accelerometer method, as outlined in a later section.

Speed and height are usually obtained from measurements of pitot and static pressures, using standard pitot static heads or static vents, connected to air speed indicators and altimeters in the automatic observer. These measurements are themselves subject to compressibility corrections. There is in the first place the well known air speed indicator calibration correction, $\Delta_1 V$, arising from the fact that the pitot pressure is a function of the Mach number as well as the A.S.I. This correction is now so familiar that it need not be discussed here. The second part of the correction arises from the fact that the static pressure coefficient $p_1/\frac{1}{2}\rho_1 V_1^2$ at any point of the wing pressure field varies with Mach number, so that the position error correction is a function of Mach number as well as A.S.I. It is usual to assume that the pressure at the static source varies with Mach number in accordance with the Glauert law. There is some uncertainty about this assumption when applied to a leading edge head, but since in this case the whole correction is usually small, the uncertainties in the assumption are not very important. This correction to the static pressure ceases to be strictly applicable when shock waves are found on the wing. Under these conditions there is no entirely satisfactory method of position error correction. Some actual measurements of position error at high Mach numbers have been made at the R.A.E. by flying the test aircraft past a Lancaster flying at a fixed height and speed. The test aircraft was photographed as it flew past the Lancaster, and the altimeter readings in the two aircraft recorded at the same time. Further work on these lines is needed before a fully satisfactory method of position error correction can be established for the highest Mach numbers (above about 0.85). It appears, however, that the present methods of correction are reasonably applicable up to about 0.85, and that the error is unlikely to be large at higher Mach numbers if a standard leading edge pitot-static head is used. An underwing head is unacceptable once shock waves have begun to form on the wing, since the shock wave may, for example, move to a position just behind the static holes and the correction will become very large and impossible to estimate.

In measuring speed and height in high speed dives by the pitot-static method, the

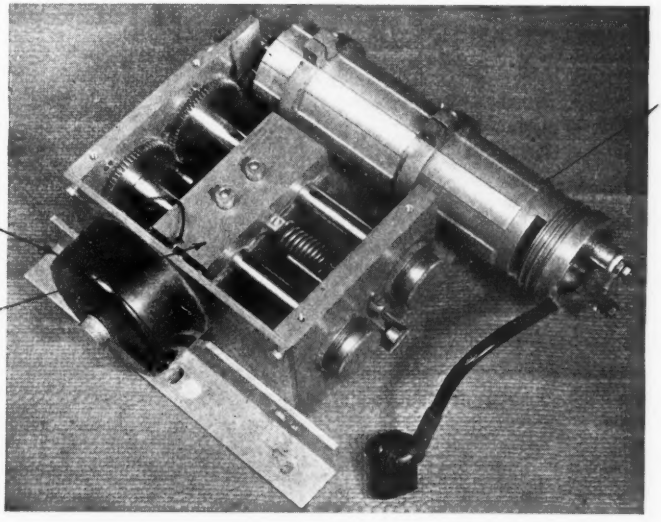


Fig. 2.
Longitudinal accelerometer used for drag measurement in flight.

A.S.I. and altimeter readings must also be corrected for lag in the tubing due to the rapid changes of pressure. It can be shown that the pressure drop ΔP along a tube of length l and internal cross-section S_T and diameter d is given by

$$\Delta P = [(d\rho/dt)/\rho]\mu K$$

where $K = (128l/\pi d^4)(\frac{1}{2}lS_T + Q)$

ρ = air density

μ = coefficient of viscosity

Q = volume of altimeter or A.S.I.

This can be written:

$$\Delta P = V_d \mu K \times (2.93 \times 10^{-5})/(1 - 6.88 \times 10^{-6}h)$$

where V_d = rate of descent $= (dh)/(dt)$

h = height (ft.).

It should be noticed that this correction is proportional to the fourth power of the tube diameter. For a typical system consisting of a standard pressure head at the wing tip connected to an air speed indicator altimeter, and rate of climb indicator, if the tubing is about 5/16 inch O.D. dural the lag correction is reasonably small, and need not be very accurately determined, even for the steepest dives.

In addition to the lag in the connecting tubes there is also a mechanical lag in the recording instruments. Some experimental measurements of the lag for several systems showed that the total lag could be expressed in the same form:

$$\Delta P = [(d\rho/dt)/\rho]\mu K_1$$

where K_1 is related to K by the relation

$$K_1 = 1.5K + 1.1 \times 10^9.$$

In practice, it is usual to install two altimeters in the automatic observer, connected by about 4 ft. of small bore tubing. The value of K_1 is then calculated for each of the instruments connected to the pressure source, and also for the connection between the two altimeters. The height lag for any of the instruments is then given by

$$\Delta h = \frac{K_1 \text{ (for instrument)}}{K_1 \text{ (between altimeters)}} \times$$

$\times$ difference between altimeter readings.

This provides a simple and direct method of applying the correction in terms of the observed readings of the two altimeters.

The pitot-static method of measuring speed and height, in spite of the complication of the connections discussed above, still remains the most convenient method of measuring speed and height at high Mach numbers. The increasing uncertainties at the highest Mach numbers, however, make it desirable to consider alternative methods. The most important of these alternatives is the use of radar.

A modified S.C.R. radar gun-laying set has been used at the Royal Aircraft Establishment to provide records of elevation, azimuth and range of an aircraft in a high speed dive. From these records, tape measure height and speed could be calculated throughout the dive. It was found the speed and Mach number could be measured in this way to an accuracy of about $\pm$ one per cent. The main disadvantage of the method is the large amount of computing involved in deriving the speeds.

Mach number is usually calculated from the measurements of air speed and height, but it is essential in addition to provide the pilot with a Mach-meter giving a direct indication of the Mach number. The principle of this instrument depends on the fact that the Mach number can be expressed in terms of the total head H_o and the static pressure P_o through the relation

$$\tfrac{1}{2}\gamma M^2 (1 + M^2/4 + M^4/40 + \ldots) = (H_o - P_o)/P_o$$

The instrument thus consists of an A.S.I. pressure capsule where deflection is proportional to $H_o - P_o$, and an altimeter capsule having a deflection proportional to P_o, with a suitable linkage for deriving the ratio between the two movements, so that the movement of the pointer depends on $(H_o - P_o)/(P_o)$. It can then be calibrated to read Mach number directly. It is, of course, subject to position error corrections.

It is obvious that high Mach number flight research demands a high degree of skill and determination on the part of the pilot. The compressibility effects with which he has to cope are fundamentally different from any of the effects experienced in flight at low Mach numbers; and the action needed to anticipate and prevent the development of a dangerous situation is often quite different from that which might be expected from low speed experience. In these circumstances, when investigating a high Mach condition which has not previously been explored, it is essential to approach the highest Mach numbers in small steps, analysing the result of each flight carefully before proceeding with the next, so that the development of any large changes of trim, instability, control ineffectiveness or any other dangerous effects may be anticipated. This obviously demands not only very close co-operation between

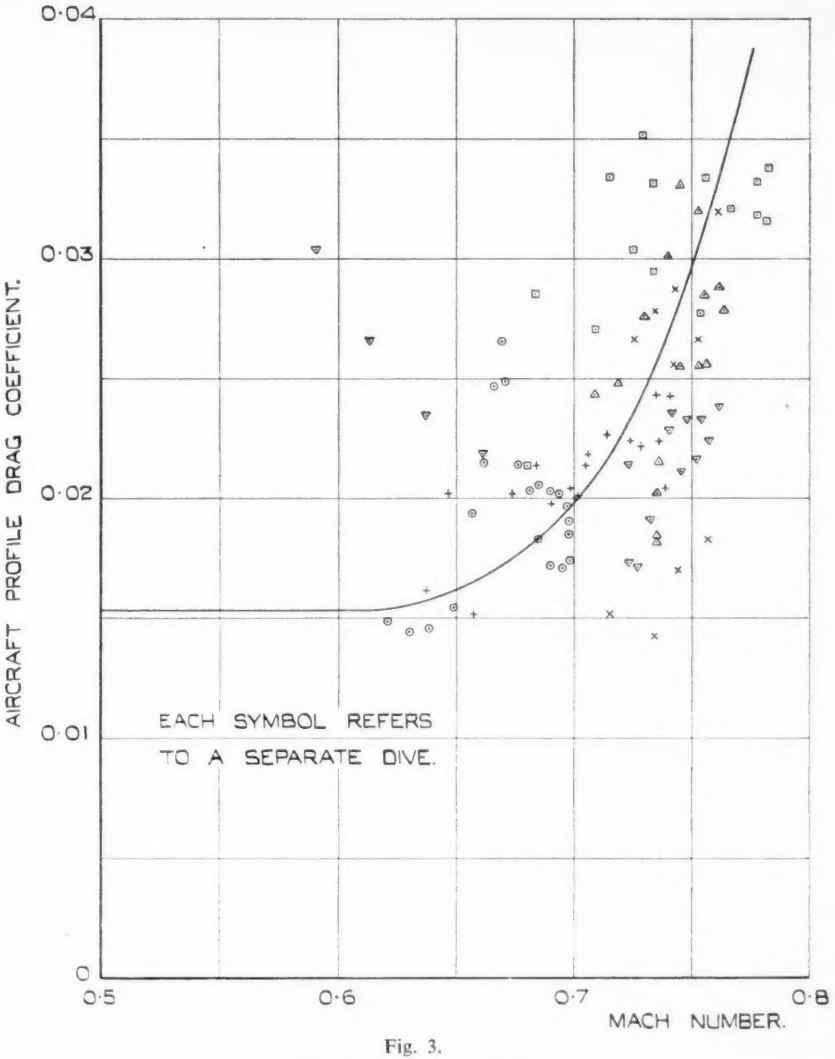


Fig. 3.
Meteor I (short nacelles).
Typical set of dive results using the energy method.

pilots and technicians, but also a considerable understanding on the part of the pilot of the technical background involved.

The Royal Aircraft Establishment has been fortunate in having the services of a number of pilots during the past few years who have displayed the necessary qualities to a very high degree, and much of the credit for the experimental results discussed in the following pages belongs to them.

4. COMPRESSIBILITY EFFECTS ON DRAG.

4.1. MEASUREMENT OF OVERALL DRAG OF AIRCRAFT IN DIVES.

The first measurements of the overall profile drag of aircraft at high Mach numbers were made some five years ago, by observing the variation of speed and altitude in steady dives and computing the drag from the con-

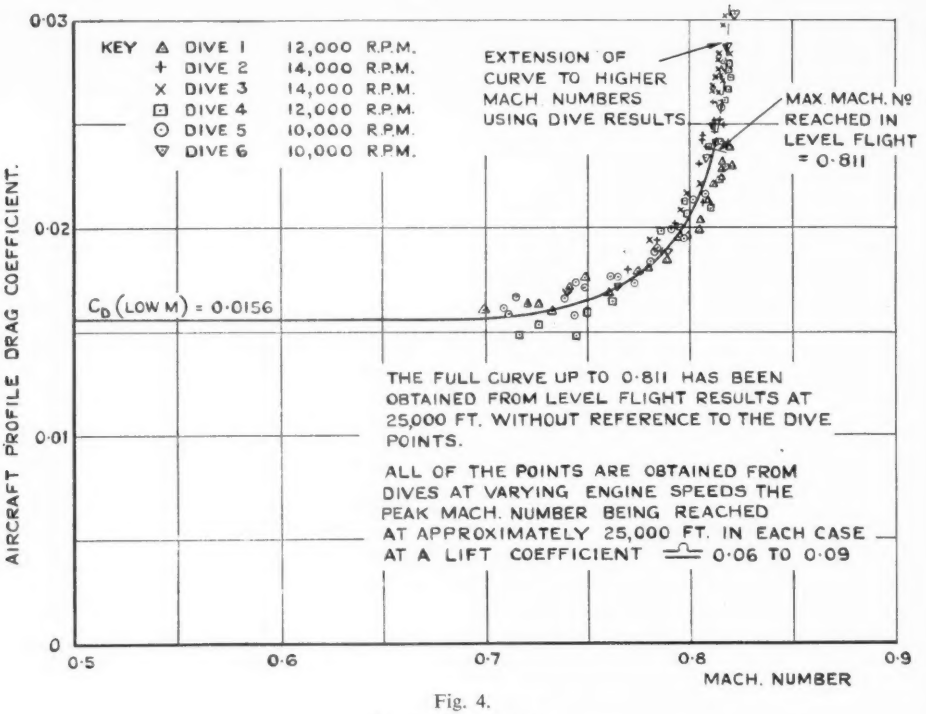

KEY
DIVE 1 12,000 R.P.M.
DIVE 2 14,000 R.P.M.
DIVE 3 14,000 R.P.M.
DIVE 4 12,000 R.P.M.
DIVE 5 10,000 R.P.M.
DIVE 6 10,000 R.P.M.
EXTENSION OF CURVE TO HIGHER MACH NUMBERS USING DIVE RESULTS
MAX MACH. Nº REACHED IN LEVEL FLIGHT = 0·811
C_D (LOW M) = 0·0156
THE FULL CURVE UP TO 0·811 HAS BEEN OBTAINED FROM LEVEL FLIGHT RESULTS AT 25,000 FT. WITHOUT REFERENCE TO THE DIVE POINTS.
ALL OF THE POINTS ARE OBTAINED FROM DIVES AT VARYING ENGINE SPEEDS THE PEAK MACH. NUMBER BEING REACHED AT APPROXIMATELY 25,000 FT. IN EACH CASE AT A LIFT COEFFICIENT = 0·06 TO 0·09
AIRCRAFT PROFILE DRAG COEFFICIENT.
0·03
0·02
0·01
0
0·5
0·6
0·7
0·8
0·9
MACH. NUMBER

Fig. 4.
Meteor IV EE 454.
Comparison of aircraft drag measured in level flight and in dives.

servation of energy. This method gave a reasonable general indication of the increase in drag coefficient at high Mach number, but the accuracy obtained was generally poor. Fig. 3 shows the results obtained in a typical set of measurements, using this method. In this example a steep angle of dive (up to 45°) was necessary in order to achieve the required Mach numbers; the inaccuracies are usually lessened if the angle of dive is less.

A much better accuracy can be achieved by using a longitudinal accelerometer to give a direct measurement of acceleration along the flight path. The accelerometer usually used at the R.A.E. for these measurements has already been described, and the standard of accuracy possible, with a careful application of this method, is illustrated in Fig. 4. The accelerometer is mounted near the C.G. of the aircraft, with its axis parallel to the important part of the estimated flight path. In practice, since the attitude of the aircraft varies slightly during the dive, it is impossible to ensure that the axis of the accelerometer remains parallel to the flight path throughout the dive. A small correction is therefore necessary to allow for this. It can be shown in fact that, to a sufficient order of approximation, if R is the reading of the longitudinal accelerometer at any point of the dive (in "g" units), n the normal acceleration, and ϕ the angle between the axis of the longitudinal accelerometer and the flight path,

$$(D-T)/(W)=R+n\phi$$

where D is the total drag of the aircraft, W its weight, and T the engine propulsive thrust.

The angle ϕ is obtained either from measurements of the aircraft incidence, using an incidence vane as described in the previous section, or from estimates based on wind tunnel tests. No great accuracy is needed in the determination of ϕ, since the correction term $n\phi$ is usually very small, provided that the axis of the longitudinal accelerometer has been set with reasonable care. It is usually sufficiently accurate to use an estimated value of thrust in evaluating the drag, but if not it

can be measured in the case of a jet engine, in the way described later in this section.

The value of D obtained in this way includes, of course, the induced drag. In general, however, the induced drag during the important part of the dive rarely exceeds about 2 per cent. of the total drag, so that an estimated correction, based on measurements at lower speeds and ignoring any possible variation in effective induced drag with Mach number, is sufficiently accurate in determining the profile drag.

The attainment of a high standard of accuracy in this method is dependent on the maintenance of steady conditions in the dive, particularly the avoidance of any sideslip, and on the correct adjustment of the longitudinal accelerometer. A higher degree of damping is necessary than in most other accelerometer measurements as this helps to reduce inaccuracies caused by small and comparatively rapid variations in the flight path. A record of the measurements made in a typical dive during the course of tests to determine drag at high Mach numbers is shown in Fig. 5.

The results of drag measurements at high Mach number on several aircraft are given in Fig. 6. A number of interesting conclusions can be drawn from these curves. It will be seen, for example, that at a Mach number of about 0.82, the increase in profile drag coefficient of a Spitfire without guns, is about the same as that of a Meteor, in spite of the latter's wing nacelles. Below this Mach number, the Spitfire drag increase is actually greater than that of the Meteor, while above 0.82, the drag of the Meteor appears to be increasing much more rapidly than that of the Spitfire. This may be partly due to the farther aft position of the maximum thickness of the Meteor wing section, and partly to a rapid worsening of the nacelle wing interference drag at Mach numbers above 0.8.

The drag of a Meteor with the original short nacelles is also included in Fig. 6. The much earlier drag rise compared with the long nacelle Meteor was caused by an earlier breakaway in the nacelle-wing junction. Photographs of wool tufts showed this breakaway beginning at a Mach number of about 0.72 on the short nacelled aircraft, and becoming severe at 0.75. With the lengthened nacelles the tufts do not become wildly disturbed until a Mach number of about 0.8 is reached. The flow through the engines appears to have no appreciable effect on the compressibility drag rise, over quite a wide range of flow.

The serious effect which certain types of excrescences may have on the drag of an aircraft is illustrated by the curves given in

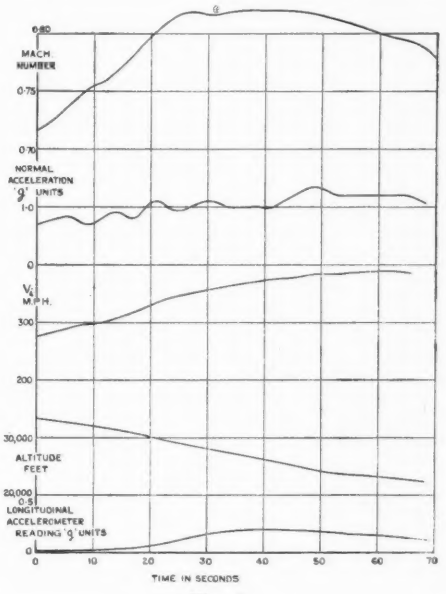


Fig. 5.
Meteor IV EE 454.
Typical time history of a dive at 12,000 r.p.m.

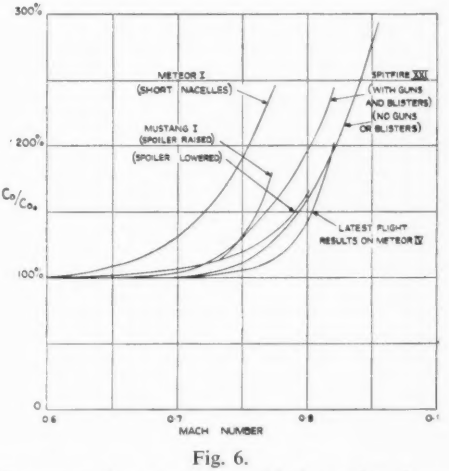


Fig. 6.
Percentage drag rise against Mach number from flight tests at R.A.E.

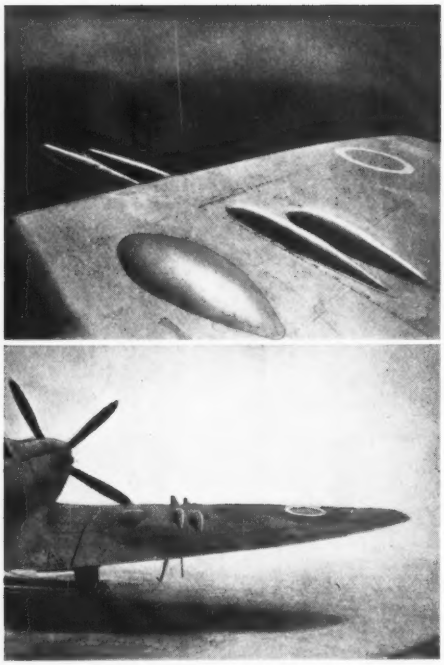


Fig. 7.
Spitfire XXI with guns and blisters.

Fig. 6 for a Spitfire with and without guns. The difference shown includes the effect of two streamlined bulges on the wing, as well as the guns themselves (see Fig. 7).

There have been no systematic tests in this country on the effect of roughness or surface waviness on the compressibility drag rise. Some measurements on an aircraft at the R.A.E., made over a period during which the surface finish deteriorated greatly, have suggested that there may be no detectable difference over a wide range of roughness. Unfortunately, the position of the transition was not measured at any stage in the tests, and it may have been far forward, even at the beginning of the experiment, in spite of the relatively good finish. None of the drag measurements at high Mach number has, in fact, been accompanied by observation of the transition. This is a pity and must clearly be rectified in the near future, particularly in view of the possible large influence of transition on the compressibility effects themselves.

4.2. Measurement of overall drag in level flight.

It is now possible on some aircraft to obtain sufficiently high speeds in level flight to enable compressibility effects to be measured more accurately than is possible in dives, and under conditions more easily controlled and interpreted. Drag measurements, for example, have been made in level flight on the Meteor used to obtain the dive results plotted in Fig. 4. The results of the level flight tests are also plotted for comparison in Fig. 4. It will be seen that the agreement is excellent.

In these level flight measurements the drag is obtained by deriving the thrust in flight at a series of heights and engine r.p.m., from measurements of total head and temperature in the jet pipe. The derivation depends on the fact that the gross thrust of a jet engine can be expressed in terms of the total head in the jet pipe and the ambient atmospheric pressure, while the mass flow can be expressed in terms of these variables and the total head temperature in the jet pipe. If, then, a bench calibration is made to derive the form of these expressions, for a particular jet-pipe pitot and thermocouple, the net thrust for any flight condition can be directly determined. In general it is sufficiently accurate to rely on a single pitot in the jet pipe, since the variation with height in total head distribution across the jet pipe is usually negligible.

4.3. Measurement of section drags at high Mach number.

The measurements of compressibility effects on overall drag discussed in the previous section are valuable in enabling us to analyse the effect of Mach number on the performance of these aircraft, and in helping us to estimate the performance of future high speed aircraft. In order to understand more fully the factors governing the drag rise, however, and to obtain systematic comparisons with model tests, it is essential to try to measure compressibility effects on the local drag coefficient at a particular section of the wing.

Two methods of doing this have been tried; the first, by obtaining detailed pressure distribution over a section of the wing to derive the form drag coefficient by integration; and second by measuring the distribution of total pressure in the wake and calculating the profile drag coefficient.

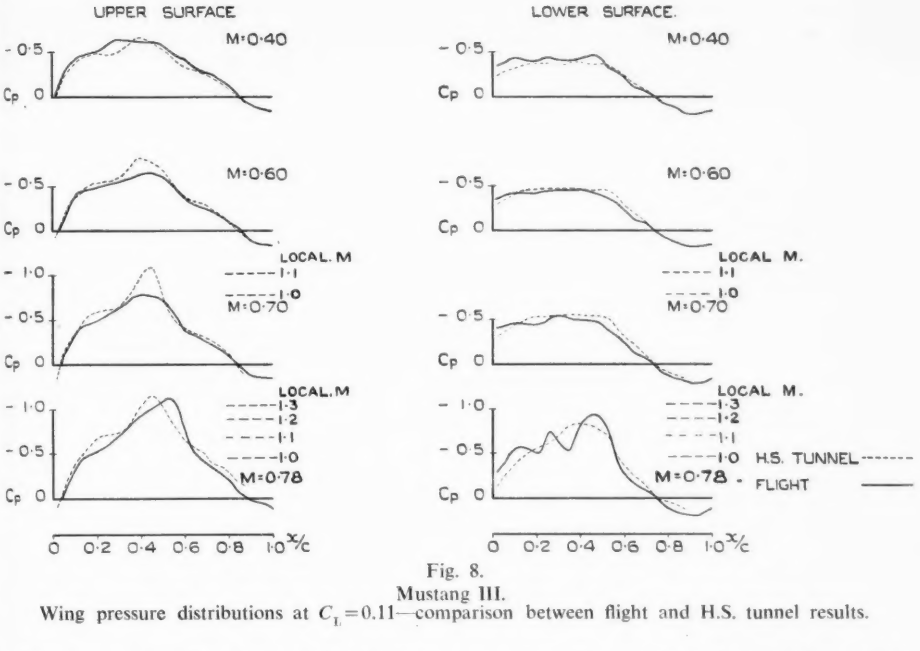


Fig. 8.
Mustang III.
Wing pressure distributions at $C_L = 0.11$—comparison between flight and H.S. tunnel results.

The first method has been tried with some success at the R.A.E. on a single-engined aircraft. There were 40 pressure holes in the test section and these were connected to air speed indicators in an automatic observer, with a camera taking photographs automatically at two-second intervals in steady dives from about 40,000 ft. In this way sufficiently accurate pressure distributions were obtained to enable the form drag of the section to be calculated for a range of Mach numbers up to a maximum of 0.82. A typical set of the pressure distributions obtained is shown in Fig. 8 and the corresponding variation of form drag with Mach number is given in Fig. 9.

Figures 8 and 9 also include, for comparison, the results of similar measurements made in the High Speed Tunnel at the R.A.E. The test section of the tunnel model represented exactly the full-scale aircraft without any distortions caused by the loads present in flight. Measurements of the distortion of the test section were made in flight and the maximum deviation was found to amount to less than 1/10 inch at 450 m.p.h. E.A.S.

It should be mentioned that this small degree of distortion was achieved only after an ammunition panel on the top wing surface had been strengthened. Before this was done the flight pressure distributions showed a large suction peak which was not present in the tunnel tests.

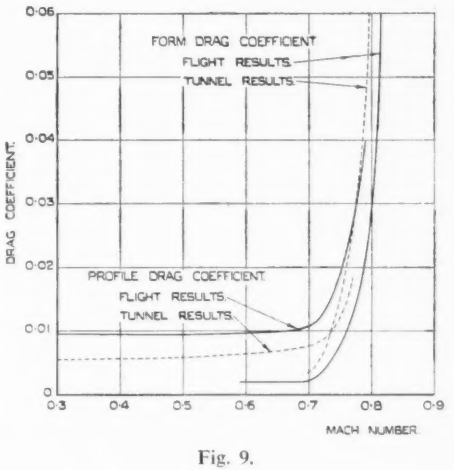


Fig. 9.
Mustang.
Comparison of wing section profile and form drag coefficients from flight and tunnel tests.

The second method of investigating the drag coefficient of a wing section in flight, by measuring the distribution of momentum in the wake, is somewhat less laborious than the pressure distribution method, but has two disadvantages. First, the width of the wake is so great at high Mach numbers that a large pressure comb has to be used. The comb must be about half the wing chord in width. Second, the existence of considerable side flows in the region behind the shock wave make the calculation of the section profile drag from the wake somewhat unreliable.

The Mustang pressure distribution tests discussed above were to have been followed by wake measurements with a wide comb. Unfortunately, before these tests could be made, the aircraft was destroyed in an accident. Since then the results of similar tests made in America have been published, and some of these results are given in Fig. 10. A profile drag curve calculated from these wake measurements is included in Fig. 9, but this curve is not thought to be very reliable, for the reason mentioned above.

The pressure distributions and wake measurements provide an interesting picture of the mechanism of the drag rise and this will be discussed in detail in the next section.

4.4. Origin and analysis of the drag rise.

It is usual to assume that the drag increase at high Mach number is associated partly with the loss in head across the shock wave, and partly with a separation on the wing surface in the neighbourhood of the shock wave. This assumption appears to be confirmed by Fig. 10, and calculations have been made in a number of cases to assess the relative contributions of the two components of the drag rise, The assumption also appears to be confirmed by observations of wool tufts on the surfaces of wings at high Mach number. In the case of the Mustang, for example, tufts on the upper wing surface began to get disturbed at a Mach number of 0.74, and became vigorously disturbed over the whole wing aft of about the half chord line at a Mach number of 0.79.

Unfortunately, this is an over-simplification of the problem. In the first place, an examination of the pressure distribution curves of Fig. 8, and of the derivation of the form drag

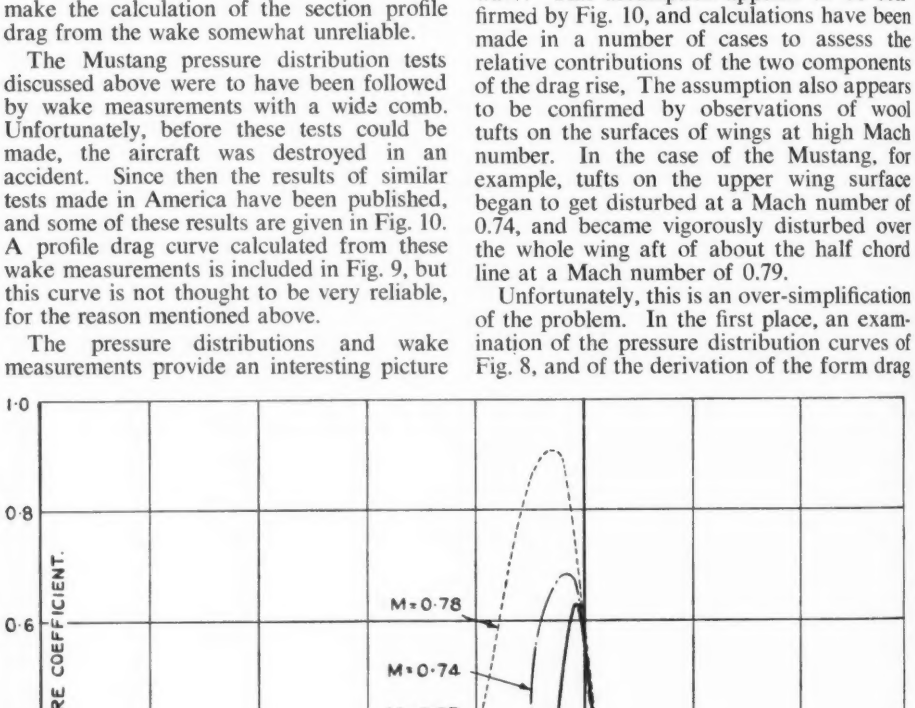


Fig. 10.

Compressibility effect on wing wake.
Wing section modified NACA 44 series. Maximum t/c 14 per cent. at 0.40C (NACA. TN. 1190).

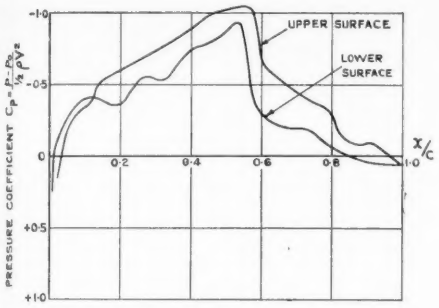


Fig. 11.
Mustang.
Wing pressure distribution at $M = 0.82$ from flight results.

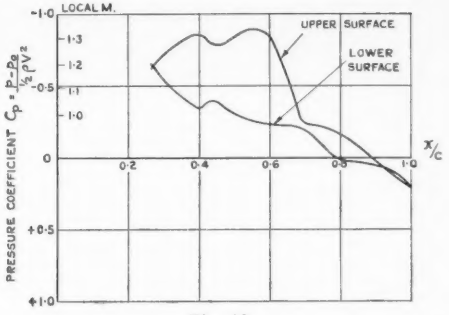


Fig. 12.
Spitfire.
Wing pressure distribution at $M = 0.85$ from flight results.

from them, shows that, even at the highest Mach number reached, almost the whole of the drag rise is associated with the formation of the supersonic region ahead of the shock wave and only a small fraction of the rise is associated with the change in pressure over the region of the wing from the shock wave to the trailing edge. Moreover, a positive pressure gradient is maintained right up to the trailing edge, and the pressure at the trailing edge is still positive, even at the highest Mach numbers reached (0.82 on the Mustang, 0.85 on the Spitfire: see Figs. 11 and 12). There is, therefore, no separation in these cases.

All that, in fact, does happen in these cases is a rapid thickening of the boundary layer behind the shock wave, and it is the existence of this thick turbulent layer which causes the violent disturbance of the wool tufts on the wing surface. (The unreliability of surface tufts in investigating separation effects is well known in low speed flight work.) The widening of the wing wake observed in Fig. 10 is partly caused by the thickened boundary layer, and partly by the loss in head at the base of the shock where it interacts with the boundary layer.

It is possible that on most wing sections a true separation will eventually occur at sufficiently high Mach numbers and when it does, it is likely to be accompanied by a severe accentuation of compressibility effects. There is evidence that this does occur on a Mustang at Mach numbers above 0.8. In the meantime, there is still a great deal to learn about the inter-action of the shock wave and the boundary layer, and its effect on the drag rise in particular. Research in flight clearly has a most important contribution to make to this problem, in view of the obvious importance of Reynolds number effects. The next step should be to try to correlate the compressibility effects with the position of the transition.

5. COMPRESSIBILITY EFFECTS ON LIFT.

Wind tunnel tests have shown that compressibility effects on lift consist, in general, of a change in the slope of the lift curve, a change in the angle of zero lift, and a variation in the maximum lift coefficient. The most important of these effects is the variation in maximum lift coefficient with Mach number. Unfortunately, this effect is difficult to measure in flight, for the following reasons: —

(*i*) The stall is usually complicated at high Mach number by the presence of other compressibility effects, such as trim and stability changes, or buffeting.

(*ii*) A high Mach number stall can only be achieved in a pull-out or a turn, even at the highest attainable altitudes, and under these circumstances the reliable measurement of speed becomes difficult.

For these reasons most of the attempts which have been made to measure maximum lift in flight at high Mach number can be regarded only as giving a general indication of the maximum usable lift at high Mach number. At the lowest Mach numbers the tests define in every case a true maximum lift coefficient. As the Mach number is increased, a stage is reached in most cases when the lift becomes limited by trim or stability changes or by buffeting before the true stall is reached (which of course limits the lift just as effectively as a true $C_{L\max}$). The lift coefficient is

then usually limited over the complete speed range somewhat as illustrated in Fig. 13. Thus at Mach numbers around 0.8 the lift may be effectively limited to a value as low as 0.2.

In the cases where a true maximum lift did appear to have been reached in flight at sufficiently high Mach numbers, a comparison with tunnel tests is given in Fig. 14. This diagram, and certain other general evidence on the subject, suggests that scale effect on maximum lift coefficients decreases in importance at high Mach numbers. This is perhaps understandable, since the nature of the stall changes with increasing Mach number, the loss of lift being eventually associated with the limitation on the pressure coefficient on the top surface, combined with the development of the suction on the bottom surface, rather than with a breakaway of flow.

In practice, the important differences between model and full scale in this connection are likely to arise from the fact that at high Mach numbers the particular form of limitation imposed on the lift of the full-scale aircraft may not show up at all in the model tests. For example, this would be the case in general if the lift of the full-scale aircraft is limited by buffeting. It is obviously of the utmost importance to try to develop a method of interpreting model tests so that any buffeting limitations may be established without resorting to flight tests.

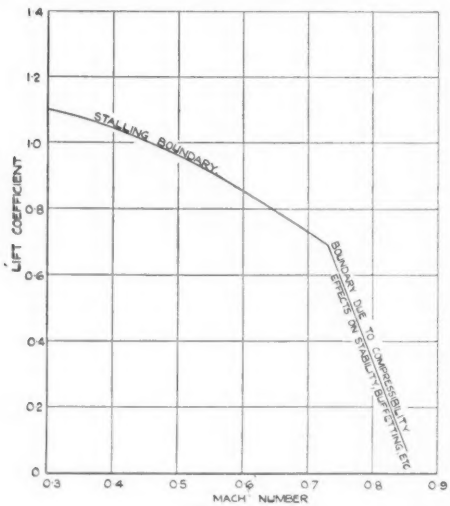


Fig. 13.
Typical example of compressibility limitations on lift.

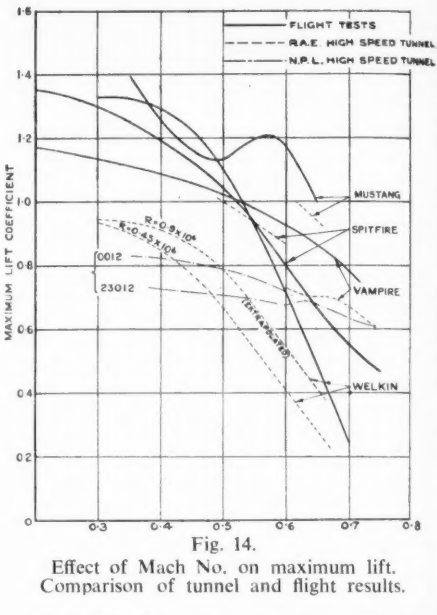


Fig. 14.
Effect of Mach No. on maximum lift. Comparison of tunnel and flight results.

6. STABILITY AND CONTROL.

6.1. General background.

At low speeds, in the absence of compressibility and aeroelastic distortion effects, the elevator angle needed to maintain any particular steady flight condition on an aircraft with a given tailplane setting and a given C.G., is, to a first approximation, a function only of the lift coefficient in that condition; and the elevator hinge moment coefficient is a function only of the tailplane incidence and the elevator and tab angles. Under these conditions the simple linear treatment of the longitudinal stability problem, originated by Gates, is applicable.

At high speeds the elevator angle needed to trim in any condition is a function of the Mach number as well as the lift coefficient; and the elevator hinge moment coefficient is also dependent on Mach number. Under these circumstances the linear treatment is no longer applicable, and even the extended analysis of Gates and Lyon (R. & M. 2028) is of somewhat doubtful validity in the region beyond the shock stall, when large and rapid variations in the derivatives may be occurring. The extended theory of R. & M. 2028 does, however, provide an invaluable foundation on

which to base the analysis of compressibility effects on stability. This theory is now familiar to most people, but those aspects which will be essential to the clear understanding of the following sections will be summarised briefly here.

The longitudinal stability and handling qualities of an aircraft are defined in terms of two factors, the static margin K_n and the manœuvre margin H_m.

The static margin at any speed V is defined by $K_n = -(dC_m)/(dC_R)$ where C_R is the resultant force coefficient on the aircraft, and $(dC_m)/(dC_R)$ denotes a *total* differential, assuming C_R and V to be connected by the relation $C_R \rho V^2 = a$ constant. With this definition it can be shown that the condition for static longitudinal stability is that K_n shall be positive.

The static margin can be written in the form

$$K_n = (V/2C_R)(dC_m/dV) = -\bar{V}A_2(d\eta)/(dC_R) \quad . \quad (1)$$

where A_2 denotes the elevator effectiveness at the speed V, and $\bar{V}$ is the total volume.

Provided that the elevator effectiveness remains positive the condition for static longitudinal stability with stick fixed can therefore be written:

$$(d\eta)/(dC_R) < 0$$

which is of course the form of the criterion directly applicable to flight testing.

The neutral point is defined as the C.G. position for which $K_n = 0$, and the C.G. margin is the distance of the C.G. in front of the neutral point.

Similarly, the stick free static margin, K_n' can be expressed in the form:

$$K_n' = -\bar{V}A_3(d\beta)/(dC_R) \quad . \quad (2)$$

where β is the tab angle needed to trim ($C_H = 0$), and the condition for stick free static stability is that $(d\beta)/(dV)$ shall be negative.

The manœuvre margin H_m is proportional to the stick force or stick movement required to maintain a normal acceleration of one g, and may be expressed in the form

$$H_m = -\bar{V}A_2(\Delta\eta)/(nC_L) \text{ (stick fixed)} \quad (3)$$

$$= -(\partial C_m)/(\partial C_L) - (\bar{V}A_1)/(2\mu_1)$$

$$= -\bar{V}A_2(\partial\eta)/(\partial C_L) - (\bar{V}A_1)/(2\mu_1) \quad (4)$$

where $\Delta\eta$ is the elevator movement needed to maintain a normal acceleration of ng.

$\mu_1 = (W)/(g\rho Sl)$.

A_1 = slope of tail lift curve.

Similarly the stick free manœuvre margin case can be expressed in the form

$$H_m' = -\bar{V}(A_2/B_2)(\Delta C_H/nC_L)$$

where C_H is the elevator hinge moment coefficient $= B_1\alpha_T + B_2\eta + B_3\beta$.

The general expression for the pitching moment coefficient of an aircraft with tail in any condition is

$$C_m = C_{m_0} + (h - h_0)C_L - \bar{V}[A_1(\alpha + \eta_T - \epsilon) + A_2\eta + A_3\beta],$$

where $h - h_0$ is the distance between the C.G. and the aerodynamic centre without tail and η_T is the angle between the chord of the tailplane and the wing chord.

Using this expression for C_m in equations (1) and (4) it will be seen that compressibility effects on the longitudinal stability characteristics of an aircraft, in general, will be the result of a combination of the following effects which occur at high Mach number.

(1) Variation of $C_m{}^\circ$ and aerodynamic centre.

(2) Changes in the slope of the lift curve and in the angle of zero lift for the main wing.

(3) Changes in the slope of the lift curve for the tailplane.

(4) Variation in elevator and tab effectiveness.

(5) Changes in downwash at the tailplane.

(6) Variation in elevator hinge moment characteristics.

A complete analysis into these components is essential to the clear understanding of variations in the overall stability and control characteristics of an aircraft at high Mach number. Unfortunately, such an analysis is difficult to derive from flight tests, particularly in cases where the problem is complicated by the presence of large distortion effects. Most of the flight tests discussed in the following sections are therefore confined to the measurement of overall effects of Mach number on static and manœuvre margins. The importance of attempting to analyse these effects in flight, however, cannot be over-emphasised, particularly from the point of view of obtaining direct full-scale checks on model and theoretical work. At the other extreme, it is also of the utmost importance to investigate the effect of compressibility variations in static and manœuvre margins on the overall behaviour of aircraft at high Mach numbers.

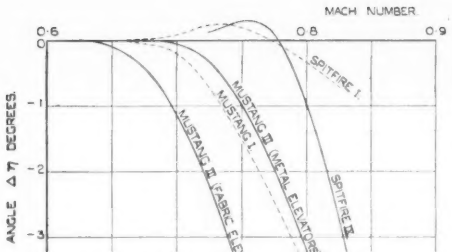


Fig. 15.
Spitfire and Mustang.
Change of elevator angle with Mach No. (measured relative to elevator angle to trim for 1 "g" at same E.A.S. at low Mach No.)

6.2. SOME TYPICAL FLIGHT MEASUREMENTS OF STABILITY AND CONTROL CHARACTERISTICS AT HIGH MACH NUMBER

6.2.1. *Trim change in dives.*

The earliest experiences of compressibility effects on the longitudinal characteristics of aircraft were concerned with the large and often dangerous changes in trim which occurred in high speed dives, and a number of measurements of these effects have been made. Fig. 15 is a typical example. It shows the change in elevator angle to trim on two Mustang aircraft, with fabric and metal elevators, and on a Spitfire. The difference between the two Mustang results was probably due to distortion of the fabric elevator. Comparable results obtained in the R.A.E. High Speed Tunnel at a Reynolds number of about two million are also shown.

It was realised that these large changes of trim in flight might be partly due to aero-elastic distortion effects. In the examples chosen, apart from the bulging of the elevator fabric on Mustang I, distortion did not play an important part. This is illustrated in Fig. 16, where elevator angles to trim have been plotted against E.A.S. for two heights. It will be seen that at the lower altitude (10,000 ft.) there is little change in elevator angle up to an E.A.S. of 440 m.p.h. ($M=0.7$) At the higher altitude (30,000 ft.) the elevator angle to trim has changed by 3° at an E.A.S. of 330 m.p.h. ($M=0.8$). Thus the change is

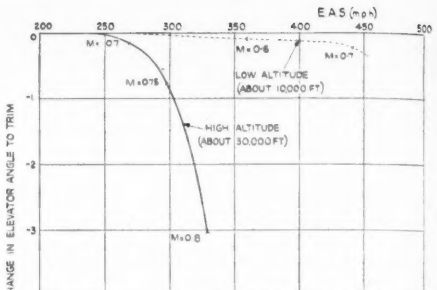


Fig. 16.
Mustang.
Elevator angles to trim at high speeds at two altitudes.

entirely associated with Mach number, and not with E.A.S. distortion.

This is not always the case. Some comprehensive tests in Germany on an Me.262, for example, illustrate well a combination of distortion and compressibility effects on longitudinal characteristics. In these tests the change of trim with speed was measured at a series of heights, and at the same time measurements were made of fuselage bending and tailplane distortion. The results are summarised in Fig. 17. It will be seen that the change in elevator angle to trim with Mach number is dependent on the height. This is due to the large effective change in tailplane setting with E.A.S., caused by distortion. Most of the initial nose-up change

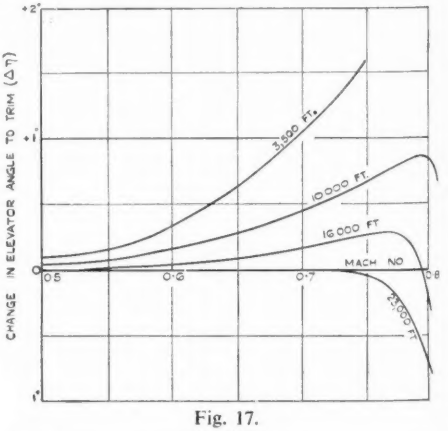


Fig. 17.
Me.262.
Mach. No. and distortion effects on elevator angle to trim.

of trim at the lower heights is due to this distortion and, if the curves of change of trim at each height are corrected for the distortion effects, all the points lie roughly on a single curve indicating a nose-down trim change beginning at a Mach number of about 0.75.

These compressibility effects on elevator angles to trim are, in general, the results of a combination of (1) changes in C_{m_0} and aerodynamic centre of the wing itself, (2) changes in downwash at the tail, due to variations in the lift distribution along the span, (3) the change in attitude of the aircraft needed to maintain the required lift. For a more or less orthodox design, the third factor will give a nose-down moment. The second factor will also give a nose-down moment if, as is usually the case, the shock wave forms first at the wing root. The first factor may work in either direction, but is unlikely to be sufficient to offset the other two. Thus, in general, the change of trim on conventional designs, in the absence of large distortion effects, may be expected to be nose-down.

The Meteor appears to be an exception to this rule, the change of trim being initially nose up, until a Mach number of about 0.8 is reached. Although this change of trim may be complicated slightly by distortion effects, it appears probable that in this case, unlike the superficially similar Me.262, the nose-up change of trim is mainly a compressibility effect. It may be due to an initial loss of lift outboard of the engine nacelles causing an increase in the downwash at the tail. The initial nose-up change of trim is followed by a nose-down change which develops rapidly beyond a Mach number of 0.8 (Fig. 18).

6.2.2. *Measurements of longitudinal stability at high Mach number.*

The changes in elevator angle to trim with Mach number discussed above, imply a change in static stability, a nose-down change

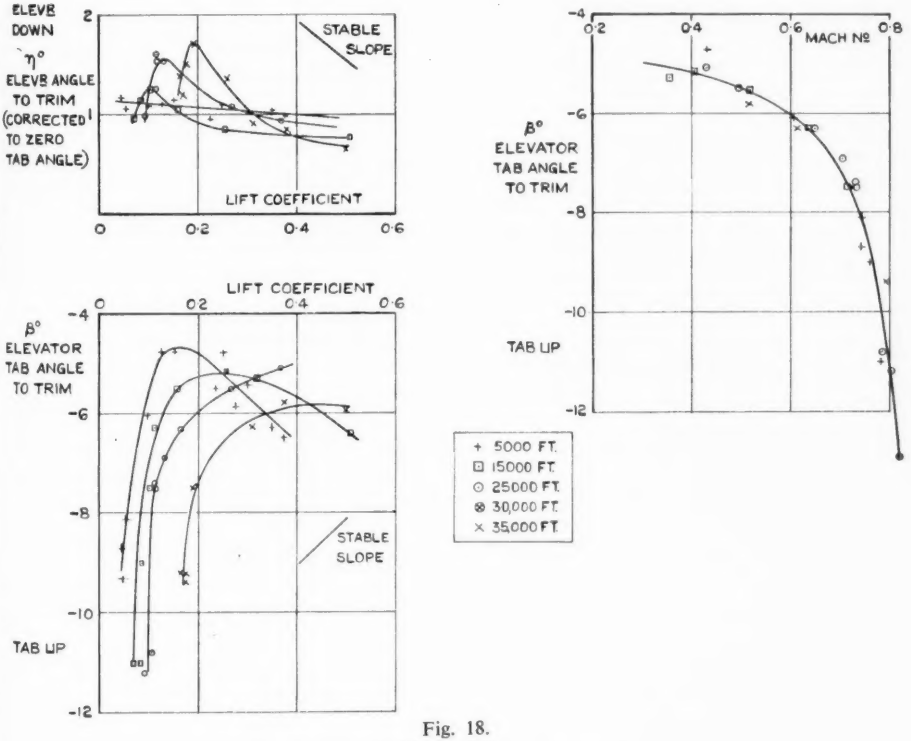


Fig. 18.
Meteor IV.
Elevator and tab angles to trim (14,000 r.p.m.).

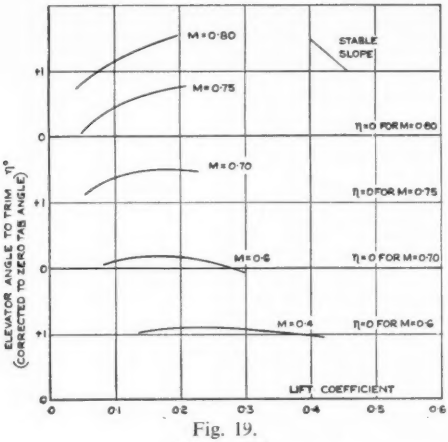


Fig. 19.
Meteor IV.
Elevator angles to trim at constant Mach numbers.

of trim at a fixed height usually indicating in particular a reduction in static margin. These changes in static stability may be very large. In the case of the Meteor, for example (see Fig. 18) there is at first a considerable increase in the stick fixed static margin with increasing Mach number, followed by a large reduction in stability, the static margin becoming negative at Mach numbers around 0.8. In many cases there is a large negative static margin at the highest Mach numbers reached. The Vampire is a good example of this (see Fig. 20). It will be seen that there is a sudden and very large change in $d\eta/dC_L$, which occurs at a certain C_L at each height. This change occurs in fact at the same Mach number at each height, and is entirely a compressibility effect. At the highest speeds reached there is a very large negative static margin at each height.

Fortunately, at these very high speeds, a large negative static margin does not appear to have as serious an effect on the overall stability characteristics as it would have at low speeds. The important factor at high speeds, is in fact, not the total differential $(d\eta)/(dC_L)$ (or $(d\eta)/(dV)$, or $(dC_m)/(dC_L)$, all of which are proportional to K_n) but the partial differential $(\partial\eta)/(\partial C_L)$ at constant Mach number. This factor also constitutes the most important part of the manœuvre margin H_m (see equation 3 above). It can be investigated in flight either by deriving curves of elevator angles to trim against C_L for fixed Mach numbers from curves such as those of Fig. 20 of η against C_L for level flight at a series of heights, or by direct measurement of manœuvre margin, or by detailed analysis of longitudinal oscillations under different conditions.

The first two methods have been used at the Royal Aircraft Establishment. The third method has not yet been developed to any appreciable extent in this country, but is being applied extensively in America, as described by Millikan in the Journal of the Aeronautical Sciences for September 1947.

Illustrations of the application of the first method to the results obtained in level flight on the Meteor and Vampire are given in Figs. 19 and 21. In the case of the Meteor there is a steady increase in $\partial\eta/\partial C_L$ with increasing Mach number, implying a reduction in stability, up to the highest Mach number reached. In the case of the Vampire, at low lift coefficients there appears to be little change in $\partial\eta/\partial C_L$ up to a Mach number of 0.75, but beyond this there is a large *decrease* in $\partial\eta/\partial C_L$, implying an increase in stability. At lift coefficients above 0.1, there seems to be a steady increase in $\partial\eta/\partial C_L$ with increasing Mach number. Incidentally, there is a serious discrepancy in this case between

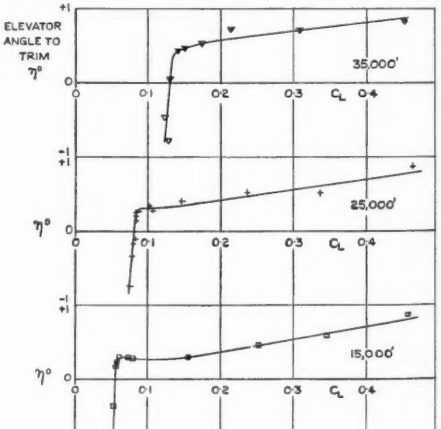


Fig. 20.
Vampire I.
Elevator angles to trim.

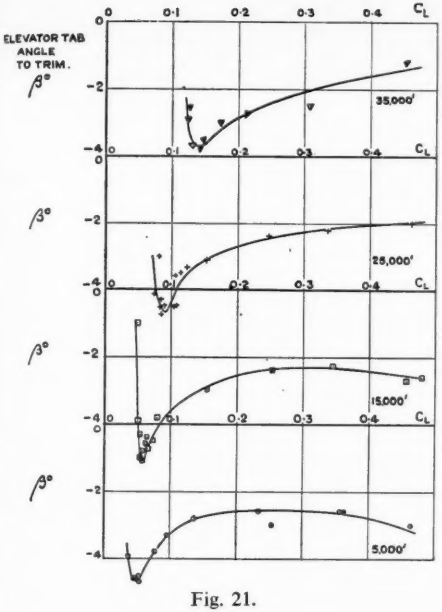


Fig. 21.
Vampire I.
Elevator tab angles to trim.

flight and tunnel tests, the latter indicating a large *reduction* in stability at $M = 0.8$ and low C_L. This discrepancy may be due to local scale effects at the junctions of the booms with the wing. It illustrates one of the most difficult problems in the interpretation of wind tunnel tests, namely, the problem of the scale effects which may arise in some region of the aircraft where the effective Reynolds number is much smaller than that associated with the mean chord of the wing.

So far we have discussed only variations in stick fixed stability with Mach number. There are, of course, corresponding changes in stick force and in stick free stability characteristics. These changes are much more complicated than the variations in stick fixed stability, since they are affected by large variations in hinge moment characteristics with Mach number, as well as by the variations in C_{m_0}, aerodynamic centre, slope of lift curve and downwash at the tail. The variations in b_1, b_2 and b_3 with Mach number may be so large that the change in stick free stability is in the opposite sense to the change in stick fixed stability. This is illustrated in Fig. 18, where the large reduction in the static stick fixed stability on the Meteor at high Mach number is accompanied by a large increase in the stick free stability (*i.e.* in $d\beta/dC_L$). The fact that the change in stick free stability is associated with compressibility rather than any other effect is illustrated by the third diagram of Fig. 18, where the tab angle β has been plotted against Mach number.

A similar effect is shown in Fig. 22 for the Spitfire. In this case the rapid increase in negative tab angle to trim as the Mach number increased was thought at first to be due to a severe loss in tab effectiveness (b_3). An independent measurement of tab effectiveness indicated, however, that there was no large variation in b_3 up to a Mach number of at least 0.85. The variation in β with Mach number is due to large changes in b_1 and b_2. Unfortunately, it was not possible from either of the tests mentioned to determine the variation in b_1 and b_2 separately. This can only be done by comprehensive measurements of elevator and tab angles to trim at a range of tailplane settings and C.G. positions, a laborious process in flight at high Mach numbers. Some idea of the extent of the variations in b_2 which may occur is given in Fig. 23, which summarises briefly some wind tunnel data on this subject.

The variation in b_2 with Mach number measured on a Meteor in flight is given in Fig. 24. The measurements were made by throttling one engine of a Meteor in level

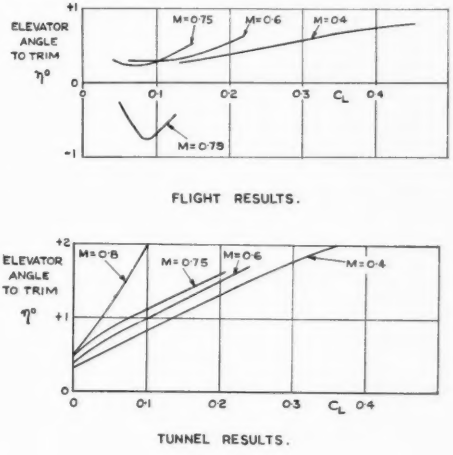


Fig. 22.
Vampire I.
Elevator angles to trim.

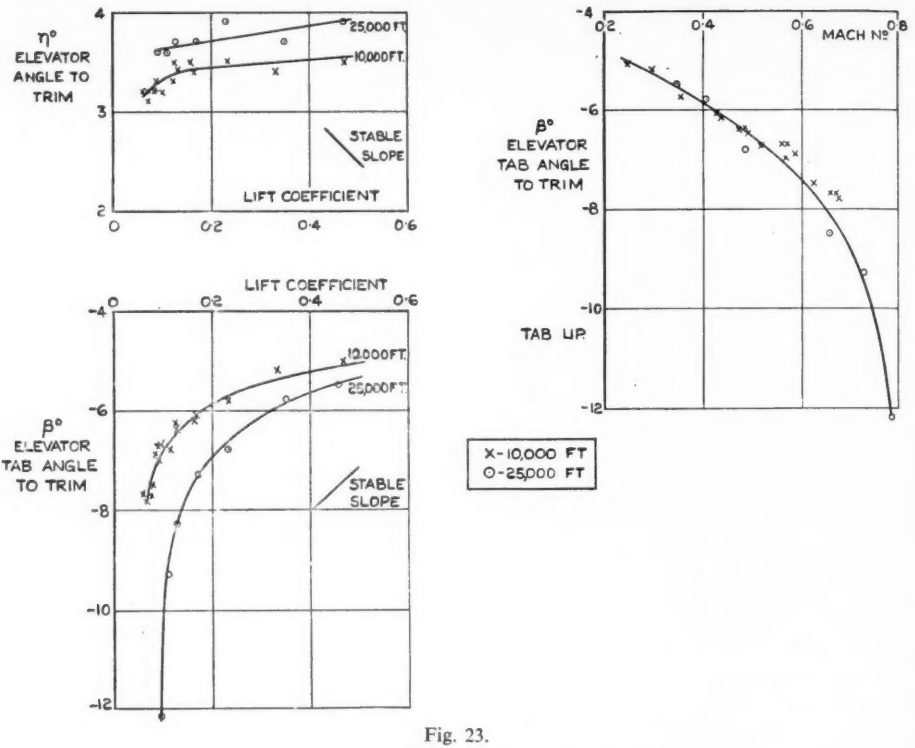


Fig. 23.
Spitfire IX.
Elevator and tab angles to trim. Engine-on—2,850 r.p.m. and + 9 in. boost.

flight and measuring the rudder angle and rudder force needed to maintain approximately zero yaw. This rather crude method gave surprisingly accurate results.

6.2.3. *Manœuvre margin at high Mach number.*

The direct measurement of manœuvre margin at high Mach number is difficult and few reliable tests have been made. Fig. 25 shows the results of some attempted measurements on a Spitfire. It will be seen that there is an initial small reduction in stick force/g, followed by a large increase. A similar initial decrease in manœuvre margin followed by a large increase was found in the Me.262 tests mentioned previously. This form of variation is unlikely to have any general applicability, since, as we have already emphasised, the variation in manœuvre margin (particularly stick free manœuvre margin) with Mach number is the result of a combination of a large number of separate effects.

A comparison of the variation in stick movement/g for a Spitfire, measured in flight and in the R.A.E. High Speed Tunnel is given in Fig. 26. The agreement is remarkably good, considering the large number of sources of possible error in an overall effect of this kind.

6.3. Overall stability characteristics at high Mach number.

The effect of the variations in static margin, manœuvre margin, hinge moment characteristics and so on, discussed above on the overall flying characteristics of an aircraft are by no means fully understood as yet. It is obvious that a negative manœuvre margin (or positive $\partial\eta/\partial C_L$) would be dangerous; but the consequences of a large negative static margin combined with a considerable positive manœuvre margin—a combination likely to occur—is not so easy to predict.

Similarly, it is obvious that if the compressibility effect on the elevator hinge

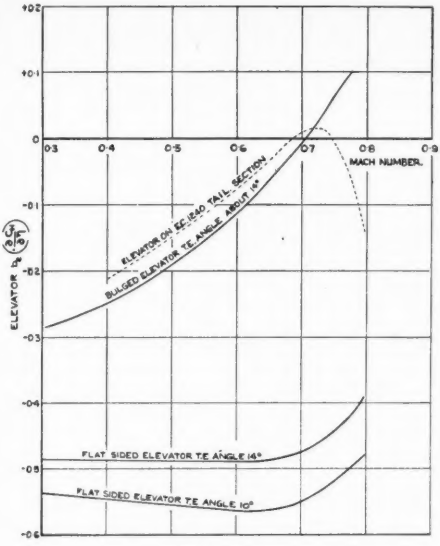

MACH NUMBER
ELEVATOR ON BEVELLED TAIL SECTION
BULGED ELEVATOR T.E. ANGLE ABOUT 14°
FLAT SIDED ELEVATOR T.E. ANGLE 14°
FLAT SIDED ELEVATOR T.E. ANGLE 10°

Fig. 24.
Variation of elevator hinge moment characteristics with Mach number (from model tests).

moment characteristics leads to a positive value of b_2 at high Mach number, the aircraft will be dangerous at high speeds. But the extent to which $(-b_2)$ may be allowed to decrease, particularly if accompanied by an increase in b_1, is not known.

There is no doubt that variations of this nature can lead to unacceptable characteristics. Many high speed aircraft, for example, experience a type of longitudinal oscillation at high Mach number which is difficult to control and, under certain circumstances, may be dangerous. These oscillations usually have a frequency of the order of one per sec. and may entail normal accelerations up to 3 or 4 g. An example is illustrated in Fig. 27, showing variations in elevator angle, stick force and normal accelerations observed in a dive on a Mustang. In most cases these oscillations are undoubtedly associated with the reduction in the numerical value of b_2 and increase in b_1 which occurs with increasing Mach number on elevators with a convex contour. Usually the oscillations have been cured, or at least delayed to a higher Mach number, by fitting cords to the trailing edge

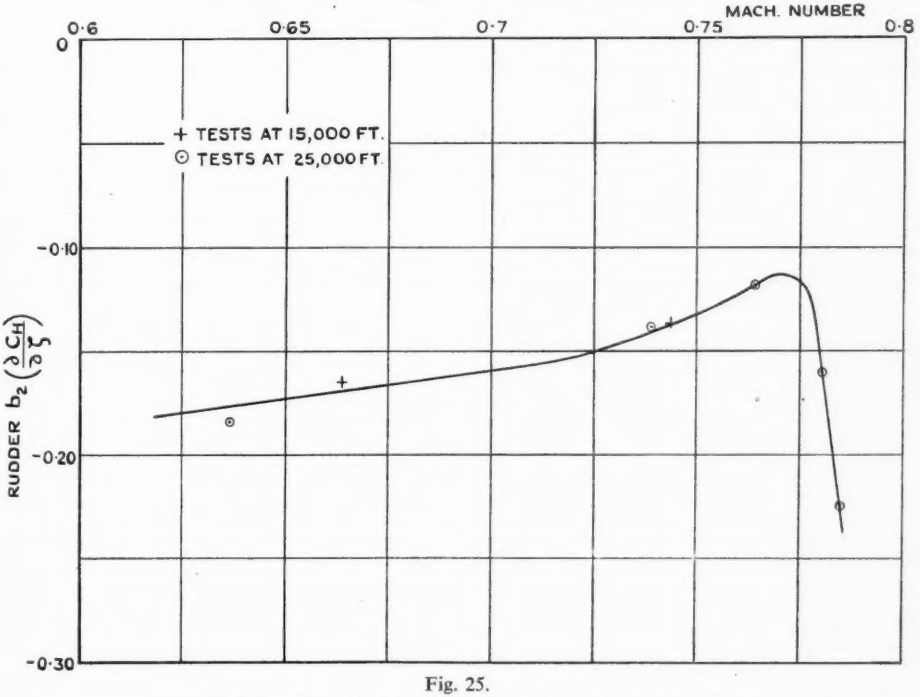
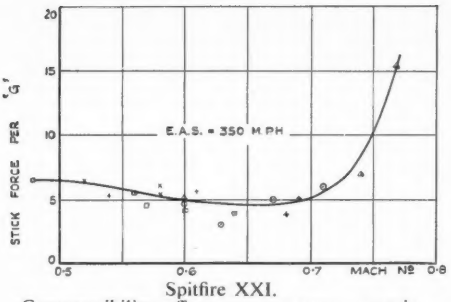


Fig. 25.
Variation of rudder b_2 with Mach number on Meteor IV.



Spitfire XXI.
Compressibility effect on manœuvre margin.

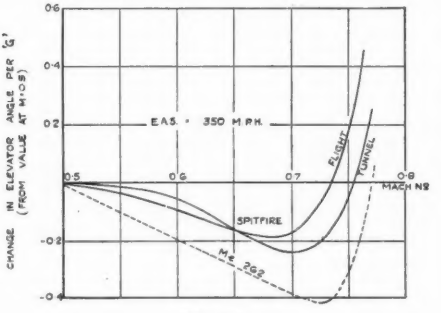


Fig. 26.
Spitfire XXI.
Variation in stick-fixed manœuvre margin at high Mach numbers.
Comparison of flight and tunnel tests.

of the elevator. Occasionally oscillations of a superficially similar nature have occurred which appeared to have been unconnected with any variation in elevator hinge moment characteristics. In these cases the oscillation may have been caused by an unstable flow over the wing at high Mach number.

It is thus clear that much more research is needed before all the consequences of the variations in stability derivatives at high Mach number are fully understood.

7. CONCLUSION.

It is hoped that this lecture will have served to emphasise the great potential value of flight testing as a means of conducting research into the problems of high speed flight. It will also have shown that there is still much to be done if we are to understand fully all that occurs even at comparatively modest Mach numbers (up to, say, 0.85). Beyond this the field as yet is almost completely unexplored in flight. The importance of investigating this region above $M = 0.85$ at an early stage in flight, on aircraft with swept-back or Delta wings, in spite of the dangers suggested by wind tunnel work, cannot be over-emphasised.

These increasing Mach numbers eventually will bring us up against new and perhaps graver risks, of a kind not previously experienced, because of the loss of control effectiveness indicated by wind tunnel tests at Mach numbers around 0.9. There is much to be said in these circumstances for trying to make preliminary experiments on pilotless aircraft or models. I do not myself believe, however, that this should deter us from pressing on with experiments on piloted aircraft to the highest possible Mach numbers. It is only by using to the fullest extent all the available resources that we can hope to solve the immense problems with which we are still faced, and there is no doubt that piloted flight research should continue to form one of the most important links in this work.

8. ACKNOWLEDGMENTS.

I wish to acknowledge gratefully the assistance I have received in compiling this lecture from past and present members of the High Speed Flight Section at the Royal Aircraft

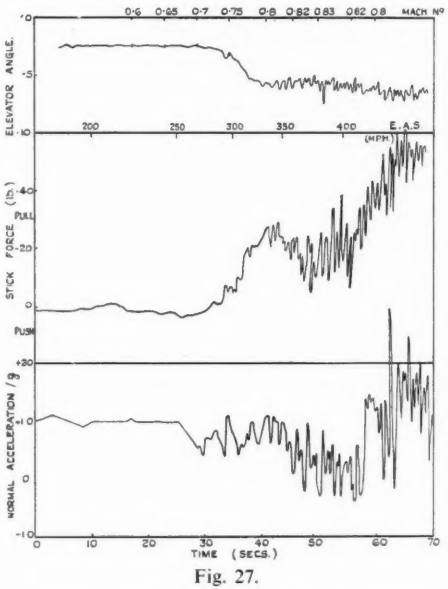


Fig. 27.
Mustang.
Elevator movements, stick force and normal acceleration in a dive.

Establishment. My special thanks are due to W. J. Charnley, D. J. Higton and R. H. Plascott, who have been responsible for most of the experimental work discussed in the lecture, and who prepared nearly all the diagrams. I would also like to take this opportunity of expressing gratitude to the pilots at the Royal Aircraft Establishment, without whose skill and determination this work would not have been possible.

Finally, I wish to record my thanks to the Chief Scientist, Ministry of Supply for permission to publish this lecture.

DISCUSSION

D. L. Ellis (English Electric Co. Ltd., *Fellow*): Designers were dependent on the full-scale people in the high subsonic flight region to a greater extent than ever before, because although high speed tunnels gave much useful information they did not give the whole story: in any case there were not nearly enough of them.

It was also a field in which instrumentation was essential. There was great scope for ingenuity and inventiveness on the part of research workers in devising and applying new methods and they should be given every encouragement. The accelerometer developed by the R.A.E. was a good example of such an application.

He had thought that when the critical speed region of a wing was reached they knew practically nothing of what happened, but results obtained by pressure plotting and by pitot traverse appeared to give a glimmering of light on the mechanism of the flow in the critical region and this work should be developed. Mr. Davies had pointed out that the pressure plotting method was laborious and he might not welcome the suggestion of elaboration of the method, but it did seem that continuous, simultaneous recording of pressure at a large number of points might lead to an advance in understanding. With luck this might lead to development comparable to that of the laminar flow wing, which was only made possible by the introduction of pitot traverse drag measurements.

What was Mr. Davies' opinion of the technique of carrying a model on a high-speed aircraft, for example, a section of wing mounted as a fin for pressure plotting or force measurements? This method had been used in the United States and seemed to offer possibilities of trying out novel wing sections and the like which they would not care to build into an aeroplane without previous knowledge.

Dr. G. P. Douglas (Royal Aircraft Establishment, *Fellow*): Mr Davies had drawn their attention to the mechanism by which the compressibility drag was transferred to the wing. He thought that in the past they tended rather to visualise the drag rise as caused by shock waves, and when they had to measure it they instinctively thought of putting a pitot behind the wing and exploring the wake. The alternative concept mentioned by Mr. Davies, was to consider the drag rise as due to the backward movement of the suction peak on the wing surface. Oswatitsch at R.A.E. had given a rough method to enable them to estimate the movement of that suction peak which caused the drag rise, and he got quite good agreement with the compressibility drag rises which had been measured. Did this way of considering the problem suggest any way of reducing the drag rise? They knew, for instance, that if under certain conditions they roughened the leading edge they could bring the suction peak forward. Experiments had shown that in special circumstances an actual reduction of drag was obtained in this way. He thought, however, that the real way to reduce the drag was to take advantage of the third dimension and use some of the three-dimensional schemes such as sweepback.

He was interested in Mr. Davies' statements about break-away and non-break-away. It was extraordinary that they got tufts towards the trailing edge oscillating so wildly, even rising 45 degrees from the surface at times, and yet the continued pressure gradient showed there was not a proper break-away. That might be so, but it was scarcely the behaviour of the usual turbulent boundary layer to which they were accustomed. They had a great deal to do if they were to understand all those matters.

G. R. Edwards (Vickers-Armstrongs Ltd., *Fellow*): They seemed to have got to the state

where, instead of pressing hard on the heels of the people who were conducting flight tests they were trying to run in front. A number of them were making passes at aircraft which were going to cruise at high Mach numbers, so high in fact that the use of sweepback appeared to be inevitable, yet the available information in this country on the effects of sweepback was limited to wind tunnel tests —the results from which, he believed it was true to say, in some ways were rather inconclusive—and flight tests of one aircraft. It meant that at this juncture they were committing the coming generation of aircraft to projects based on scanty information. Once those aircraft were designed flight test information in a year or two's time would not make much difference because the aircraft would have been committed to their basic shape and no amount of changing would put them right. The work of high speed flight testing was probably more important at this stage than ever it had been, and the correlation of the results of high speed flight tests was of the utmost importance to the future of aviation in this country.

He thought it significant that the majority of the curves in Mr. Davies' lecture were based on aircraft of the Spitfire and Mustang vintage; that there were no curves available for any aircraft that really looked like the aircraft they were now attempting to design was, in his opinion, a sobering thought. He thought a determined effort might be made in which aeroplanes flying now, with well-known characteristics, might well be subject to modifications in easy stages by applying some degree of sweepback to some part of the wing, so that they might be able to get some idea of the value of sweepback on an established aeroplane. In the data from flight tests so far available there was no indication of how much was due to sweepback and how much to other factors. The other factors could be quite appreciable.

What was Mr. Davies' opinion of the practicability of attempting to determine the part of an aeroplane at which shock waves were first occurring? So far they knew that an aeroplane produced a drag curve of a certain shape. What contribution to that curve the cockpit hood, or the nacelles, or the wing-body junction might have made they did not know. For instance, why was it that the Spitfire had reached the Mach number of .92? Why should it, when other aeroplanes had considerable difficulty in getting a much lower figure? Every aeroplane could not be designed the same shape as a Spitfire because that happened to work.

What were Mr. Davies' views on the likelihood of their knowing what it was that was making any particular aeroplane refuse to behave as it should? Was it practical to have a horizontal comb to take readings down the length of the wing in order to give them some sort of indication as to what was going on over the wing span?

No reference had been made to the characteristic which, he believed, had been evident on two or three jet aircraft, the Me.262 possessed it and he believed other aircraft had it also—directional snaking. He had read copious reports of the determined efforts the Germans made to cure the snaking on the Me.262 and so far as he remembered, they did not succeed. They merely succeeded in changing the frequency of the oscillation, but so far as he knew it was not cured. Would Mr. Davies enlarge on the snaking troubles that had been associated with aircraft with which he had been connected—he thought it had been confined to jet aircraft— and if possible could he give any clue that might enable some of them to avoid the same trouble in the first instance.

Did Mr. Davies think that in that class of aeroplane power-operated controls were inevitable? The complications of a control system which had to be triplicated took away some of the glamour that power-operated controls had for some of them. He had been attracted by them in the early days because he thought there was a reasonable hope that a mechanical solution might have got him out of the clutches of the aerodynamicists, but he had since discovered that the mechanical problems could well prove to be the worse of two evils. He knew Farnborough had approached the problem of the use of spring tabs on a high speed aeroplane. The Supermarine Attacker had performed successfully. He would like Mr. Davies' view on that because he thought it was going to be an extremely important matter.

The Industry, as much as the Ministry, had to take their share in the responsibility to produce some equipment by which means Mr. Davies and his pilots could produce some of the information that at the moment they needed so badly.

J. K. Quill (Senior Test Pilot, Supermarine Division, Vickers-Armstrongs Ltd.): He thought Mr. Davies would have convinced

anyone who was not convinced before of the importance of full-scale flight testing on this question of stability and control at high Mach numbers. The whole future of aircraft development depended upon it. The people who were trying to do this work were under the disadvantage, he thought, of having only current military types on which to work, and those aircraft were not necessarily the most up-to-date available. The time had come when they must consider building special research aircraft specifically for the purpose of full-scale research into those problems. The Americans were doing it and it ought to be done in Great Britain.

Mr. Davies had mentioned the difficulties that the pilots had in doing flight test work at high Mach numbers when diving to get the necessary speed. The difficulty about a dive was that if the pilot did get out of control in a steep dive there was nothing he could do about it. It was extremely difficult to slow up. The ideal way of doing flight research of this nature was to have a specially powerful engine. It was interesting to note that on the Douglas Sky Rocket they had an ordinary jet engine for take-off and normal flight and a bi-fuel unit for very high speed work, which presumably would enable them to reach very high Mach numbers while climbing. That would enable the pilot to slow up quickly if he got into trouble. What was Mr. Davies' opinion on the use of bi-fuel rocket units for that sort of work?

M. B. Morgan (Royal Aircraft Establishment, *Fellow*): He had always been a firm believer in getting a man into the aeroplane at the earliest possible moment, if their ultimate aim was to produce a man-carrying machine. It was important that purely experimental piloted aircraft should be built for high Mach number work, because a pilot could give information on subtle handling points unobtainable from an automatic observer. If they were producing a pilotless weapon, that was a different matter.

In the past they were badly crippled by having to do work in the dive because the pilot could not hold the Mach number steady and the altitude was changing. On the other hand, if they were working in level flight they could creep up to the desired figure slowly and see what was going on as they did so. He would stress the importance of doing these things in level flight.

Much had been said about stability and control. There he would stress the importance of great care, because of the large number of conflicting factors that were operating at high speeds and Mach numbers. What was needed was a comparison between flight tests and the high speed tunnel. The tunnel had to be the fundamental research tool for systematic work because flight work was just too long and laborious to ring the changes sufficiently. Good correlation between the flight and the tunnel must be established.

On the question of stability and control, at the R.A.E. they hoped to continue on a Meteor some earlier distortion work tests on a Mosquito, in which they had tried to separate out aeroelastic distortion and Mach number effects.

He had never been a strong advocate of power-operated controls, but he had felt that aerodynamic balance was possibly fighting a losing fight as a means of operating the controls on purely *experimental* high Mach number aircraft. In their experience hinge moments were extremely touchy things, and b_1 and b_2 flew about in all directions as they increased the Mach number. He thought it a sound move definitely to have powered controls on experimental high speed aircraft. When they had them they could put in gauges to measure the forces on controls in flight, and by doing research of that sort they might become clever enough to do without power on subsequent aircraft. But they should proceed the safe way by having powered controls on the experimental machines to give the pilots a fair chance.

Lt. Comdr. (A) E. M. Brown (Royal Aircraft Establishment, *Associate*): In the majority of flight tests the "boffins" had the annoying habit of predicting exactly what the pilot should do. They sent him up to do a job and when he came down and perhaps gave the answer as 4.8 he was solemnly told it should be 5.5 and he was messing up the "boffin's" curves by getting scatter. But, with compressibility the pilot could really tell the technicians the answer with confidence, up to a point, because after all, their forecasts were inclined to be inaccurate because wind tunnels were somewhat unreliable above Mach numbers of .8.

There was a further point on that side of testing which he thought, to a lesser degree, was characteristic of all flight testing. The business demanded the closest possible liaison between the pilots and the technicians, because every step had to be taken

gradually and under careful supervision. In that respect he would also go so far as to say that he thought the flight commander supervising the flight testing section undertaking that sort of work, should be very experienced and also have a firm grip of his pilots. There was a tendency among keen young pilots, who came from various training or non-testing units, and had flown the fairly innocuous Meteor III, to glance longingly at the more lethal Meteor IV and say, "Let me get at it and I will burst the sonic barrier wide open for you." That was dangerous.

Mr. Morgan had said that he loved to put pilots in aeroplanes to fly them at high speed. He agreed. He thought the piloted aircraft in their lifetime had as much future as the pilotless projectile. There were, of course, physiological and psychological problems connected with it, but he thought they were well on the way to overcoming them.

He thanked Mr. Davies and his team of technicians at the R.A.E. with whom he had been working, and his own pilots who had done the jobs they had seen on the screen. They had had their trials. There had been occasions when Mr. Davies' team had sent them into the air and had asked them to dive at .84, adding "I don't want any pictures below .84. Just press the camera button at .84." And when they were at that Mach number, rushing steeply downhill, and were holding on desperately to the control column with both hands and glanced round for the camera button, they found it on the floor at their feet! That was what he meant by liaison. But taking it all in all he thought Mr. Davies had a magnificent team at R.A.E., and he thought pilots and technicians were getting along well together.

H. Bateman (*Fellow*): He disagreed with the speakers who seemed to think that it was necessary to put a pilot inside a full-scale aircraft in order to get any aerodynamic measurements.

He believed that aerodynamic data at high sub-sonic speeds could best be obtained by free-flight model aircraft. The present techniques of measurement relied upon pilots pushing buttons and the aircraft returning safely. If the full scope of electronic development were used, small models of high speed aircraft could be used to obtain aerodynamic data much more quickly. Mr. Davies had already remarked, as had many others, on the great danger to the pilot during high sub-sonic full-scale flight. This danger caused the aircraft designers to go ahead slowly with improvements and the pilot to go slowly and carefully with the tests.

In the good old days when aircraft were flying at about 200 miles an hour, the fundamental work was done in wind tunnels, and the wind tunnels then had a top speed of about 80 to 100 feet per second. The aircraft designers got to work with this data and in two years produced an aircraft. It was then necessary to put the aircraft through trials in order to check whether or not there were any scale effect because of the large differences in speed and size. Now, with higher speeds, higher Mach numbers, the Mach number became much more important than scale effect, but the wind tunnel seemed to be failing them and aircraft took much longer to design and construct. Thus, if full-scale piloted aircraft had to be used to obtain fundamental data, the progress of research would be extremely slow.

If, on the other hand, the safety of the pilot could be ignored and the risk of damage to the aircraft, either during the trials or in landing, could be accepted, there would be a considerable increase in the speed of production of new models for test and a rapid advance in their knowledge of high subsonic aerodynamic data.

E. J. Richards (Vickers-Armstrongs Ltd., *Associate Fellow*): He felt that on some types of aeroplane, for instance, the high speed air liner, the high speed transport and the high speed bomber, the buffeting barrier had got a little out of place. Those aeroplanes were going to fly round the countryside with the minimum of drag, and if they had that they would have the minimum shock wave and consequently no buffet. Mr. Davies had pointed out that the apparent reduction in the Mach number barrier amounted to .01 for .1 C_L accomplished, which was to say that if, in fact, an aircraft were flown at .05 Mach number below the buffet barrier at the level flight lift coefficient it meant that quite a large excess C_L for manœuvre could be obtained without actually running on to the buffet barrier. .05 was about the Mach number difference between no drag and about 30 per cent. drag.

How was the buffet Mach number correlated with the drag rise Mach number? It seemed to him that the two came to somewhat the same. Did Mr. Davies agree that on bombers the danger of reaching the Mach

number of the buffet barrier was not so great as was at first imagined?

D. M. Jameson (Air Registration Board, *Graduate*): There was one point, which had not been mentioned, in which he thought they were very interested and that was the behaviour of the aeroplane if stalled, in the piloting sense, by gusts or over-enthusiastic manœuvring.

Mr. Davies had said that some work had been done on finding $C_{L\,max}$ at high Mach numbers. He wondered if, from this, any behaviour information was available or likely to be available in the near future?

C. N. H. Lock (National Physical Labor- *Fellow*): Being himself interested in the technique of high speed tunnel testing, he was gratified to find how much agreement between wind tunnel and flight tests had improved during the past few years. This agreement had resulted from an almost equal decrease of the flight estimates of Mach number and increase of the wind tunnel estimates.

On the subject of drag rise, he had not quite understood a statement by the lecturer which seemed to imply an avoidance of the fundamental momentum relation for drag. He still thought that any rise of drag must be associated with either the entropy rise through the shock wave, or with thickening or break-away of the boundary layer. Recent theoretical developments suggested that an appreciable local supersonic region was possible on a wing with very little drag rise. This might be obtained by suitable design of shape of section or might require suction.

However, even if the drag rise were avoided it might be more difficult to avoid a change of pitching moment. Could Mr. Davies say whether or not changes in stability or pitching moment occurred in practice earlier than, or at the same point as, the drag rise?

A. D. Young (Senior Lecturer, College of Aeronautics, *Fellow*): The possibility that instability of the shock wave might be a cause of buffeting and vibration was no doubt in the lecturer's mind, although he had not mentioned it. The instability might arise as followed. Consider a wing with a limited supersonic region adjacent to it, terminated by a shock wave in the usual way. From the point where this region began to the position of the shock the air flow just outside the boundary layer was deflected through an angle given very closely by the angle between the tangents to the surface at those two points. If the expansion were accomplished by one family of straight characteristics (*i.e.* simple wave flow) a well-known unique relation between local Mach number and stream deflection could be readily obtained. The actual expansion, however, was modified by the presence of compression wavelets reflected from the sonic boundary, and for a given deflection the Mach number increase above unity was less than that given by the simple wave theory. An examination of some German results on a number of different aerofoil sections showed that plots of local Mach number against stream deflection fell consistently and closely about a unique curve, showing the Mach number increase for a given deflection to be about one-third of that of the wave theory. It was necessary to analyse a great deal more data to establish the uniqueness of this Mach number—deflection relation before it could be confidently accepted.

Assuming, however, that this relation was, in fact, general, then consider an aerofoil with fairly flat surfaces over the rear. Once the shock on upper or lower surface had moved back to the flat portion, the possible deflection that remained was small, and so a small change in the aircraft speed or incidence might produce a large movement of the shock wave which, in turn, would result in large changes in the aerodynamic characteristics of the aircraft. The possibility of the shock wave position oscillating was then apparent, and such oscillatory movements of the shock would be accompanied by oscillations of the aerodynamic forces and moments, which might be interpreted as buffeting or vibration, particularly if accompanied by flow break-away. This led to the speculation that they should investigate the possibility of stabilising the shock wave by correctly shaping the rear parts of aerofoil sections. A few German tests had indicated greater stability of the shock by hollowing the aerofoil surface.

Mr. Davies had mentioned the possibility that the large value of $[\partial C_M/\partial C_L]_M$ might account for the considerable and rapid oscillations shown by some aircraft in a dive (as illustrated in Fig. 27.

Some years ago, Dr. Neumark and he had made some step-by-step calculations on the pull-outs of various aircraft from high speed

dives. In one of the early calculations it was noted that an aeroplane with a very large value of $[\partial C_M/\partial C_L]_M$ began to oscillate at an early stage, and these oscillations built up rapidly and very soon the aeroplane got completely out of control. A closer analysis showed that the steps taken in the calculations were too large, and the associated errors were acting, in effect, as periodic sources of disturbance exciting the aircraft. Paradoxically enough, the excessive response of the aircraft to these disturbances was found to be due to the large value of $[\partial C_M/\partial C_L]_M$, for although this term increased the damping of an oscillation once it started, it also increased the initial amplitude and frequency of the response to a given disturbance. By decreasing the steps to a sufficiently small size, the disturbances introduced could be made negligible and the calculations were able to proceed smoothly. In flight, however, there were constant sources of small disturbances present, and it seemed feasible that for conditions when $[\partial C_M/\partial C_L]_M$ was large, these disturbances might be enough to provoke a continual series of responses of appreciable magnitude; to the pilot those responses would appear as a continuous oscillation or vibration.

Could Mr. Davies offer any explanation of the positive values of $[\partial C_M/\partial C_L]_M$ shown by the Meteor and Vampire at low incidences at high Mach numbers? Were the nacelles or booms contributing to this effect by causing local shock stalls which increased the downwash at the tailplane?

Dr. G. V. Lachmann (*Fellow*): As he understood the diagrams shown by the lecturer, hinge moments, even if still manageable became somewhat erratic when M approached a critical value. With directly operated controls or power-assisters and feed back, this must result in a somewhat confusing "feel."

He appreciated that opinion was still divided on the necessity of providing "feel" with power-operated controls. He, personally, thought it inevitable to employ fully power-operated controls for large and fast aircraft; he was also an advocate of artificial "feel" in connection with power-operated controls and had been connected with the design of a device to provide synthetic "feel," *i.e.* constant stick force as a warning to the pilot. The question had occurred to him, what kind of "feel" or stick forces were considered desirable in lieu of what would actually be felt with directly operated controls when flying at a speed approaching the critical Mach number?

With stick force a function of A.S.I. the approach of M_{crit} would coincide with reaching a predetermined value of A.S.I. at a certain low altitude. But when flying at very great altitude the critical Mach number would occur at a much lower value of A.S.I. and stick forces would be much smaller for equal control deflections. Incautious operation of the controls might lead to dangerous troubles arising from compressibility effects.

Would it be desirable to have "feel" functionally controlled in some way by Mach number so that the building up of stick force would not only be a warning against creating excessive accelerations, but also against compressibility effects which might result in breaking up the aircraft before excessive accelerations were reached?

W. G. A. Perring (Director, Royal Aircraft Establishment, *Fellow*): One or two speakers had referred to the fact that the designer seemed to have leapt ahead of research and development. He supported that view and thought it might be true to say that the experimenter had at last been found out. He had sufficient margin over the designer in the past to at least put up a good show. Now he had to confess that he did not know. One thing that had struck him about the lecture was the enormous advances that had been made in technique; a good example was the use of the accelerometer to obtain drag at high speeds as opposed to the previous method involving the plotting of height and speed. He believed there was a great deal more that could be achieved in that direction. What was the lecturer's opinion? It seemed to him that the electronic field was now opening up methods of obtaining more instantaneous recording and giving far better tools than they had in the past, and he believed that these might be the right type of tools for the job.

He thought that in the future they would be far more dependent on flight testing than they had ever been in the past, if only to establish the right correlation between wind tunnel and full scale. They were there only going through what had always been the history of aeronautical development. He remembered all the heart-burning that had taken place twenty or thirty years ago on the correlation of wind tunnel and full-scale

measurements of drag. Now practically everything was in the melting pot again and they had to find a fresh basis whereby the different results could be judged against the background of experience. In the development of technique he thought they had already gone a good way to overcome a great many of the uncertainties. The good correlation which had now been found between drag measured in dives and in level flight was a promising indication of the value of this work in the future.

A good deal had been said about maximum lift at high Mach number. He would like to recall to their minds some remarks which he thought Mr. Morgan had made in his lecture "Control in Low Speed Flight,"* where, in discussing control at high speeds he produced pictures such as they had seen that night and indicated how seriously these effects limited the operation of aircraft at high altitude. They would find that the useable lift left available to the designer was getting very small indeed. He thought there was a challenge to the aerodynamic research worker to explore what were the real factors influencing the maximum lift and to see what could be done to lift the barrier of maximum lift so as to provide them with more breathing space.

The lecturer referred again to the barrier that was being set on the other side of the curve because of buffeting, and there again, there was a great challenge and one full of complexities. There seemed to be so many causes that had to be disentangled in deciding what was fixing the real buffeting barrier; the flow behind the shock, the flow at the tail, the flow, possibly, at the wing junction, or the nacelle junction. It might be due to control surface vibration, arising perhaps from changes in hinge moment characteristics; it might be coming from a general overall instability as a function of some or all of those factors. He did not share the view that they could forget this barrier. He believed it was just as important to move that area farther up to higher Mach numbers, as it was to fly inside it.

The lecturer had referred to the tuft explorations that had been made in flight, and had pointed out that the tufts gave evidence of a disturbed region of flow behind the shock, although the pressure distributions did not appear to indicate any serious flow separation. Wind tunnel work had shown that surface tufts on models could become very disturbed behind the shock, but that the depth of the disturbance was small, usually not more than 3 per cent. of the chord. Was there any evidence of the depth of the disturbance from the full-scale work?

The general question of stability seemed to him to be of importance, and the understanding of the things which were affecting the manœuvre margin. There again the factors involved were complicated; they could ring so many changes that he was wondering whether with the time and resources available they would solve them. Could they go a stage farther in the possible solution of those problems? Some speakers had raised the question of power controls. He raised the general question of whether they would not probably solve those problems from the over-all point of view by some mechanical automatic pilot that took care of all the factors and so ensured the stability of the aeroplane in an over-all sense.

In his view it was most important in the case of a high speed experimental aircraft that pilots should do the work, at least in level flight conditions. He thought it unfair to ask pilots to tackle it in the dive. Mr. Quill wished to do it on the climb. Certainly they should have enough power available to do it in level flight.

The elastic problems were also important. An aeroplane was by no means a rigid body, and he would like to draw attention to recent work which had been done by Mr. Lyons which had shown that it was not always compressibility which gave rise to their troubles. Many of them arose from the fact that the aeroplane was not rigid and that the distortion which occurred was causing many unpleasant characteristics.

MR. DAVIES' REPLY

Mr. Ellis: There was a lot to be said for the technique of models mounted on the wings which had been used widely in America, but the main snag was that the Reynolds number was not appreciably better than that which could be achieved in the high-speed tunnel. That was the chief reason why they had not developed the technique in this country. Nevertheless there was no doubt that in the trans-sonic region the Americans had attained a remarkably good series of results, and perhaps they were

* Anglo-American Aeronautical Conference, London, September 1947. Aeronautical Conference Volume, published June 1948.

wrong in not developing the method themselves. The main difficulty was that the resources needed to pursue experiments of that kind were large, and it was doubtful if they in this country could afford to pursue every promising line at the present time.

Mr. Ellis had also suggested that valuable information might be obtained at high speeds by taking continuous recordings of pressures at a series of points on the wings. He entirely agreed with this suggestion, and hoped that the electronic methods of measuring pressures in flight, at present being developed at the R.A.E., would enable such observations to be made without excessive labour.

Dr. Douglas: He had made some interesting remarks on the nature of the region of break-away. The point about roughening the leading edge was particularly interesting, but one thing to be remembered there was that in tests at small Reynolds numbers what one did to the boundary layer certainly affected the position and nature of the shock wave and, although they might move the supersonic region forward, it only occurred at the expense of a rapid thickening of the boundary layer behind it.

It was interesting to note that Oswatitsch's method of calculating the movement of the supersonic region on a wing and hence determining the drag gave quite reasonable agreement with the measured drag rise, in spite of the fact that it took no account of any drag rise due to separation or skin friction effects. This seemed to confirm the flight measurement to which he referred in his lecture, showing that nearly all the drag rise was, in fact, associated with the movement of the supersonic region, up to the highest Mach numbers reached.

He sympathised with Dr. Douglas's difficulty in understanding the wild behaviour of surface tufts behind a shock wave if there were no break-away, and hoped that some tests which were at present being made at the R.A.E. would throw further light on this problem.

Mr. Edwards: His personal opinion was that it would be unwise to consider power controls to be inevitable. They were proving to be much more difficult from the mechanical point of view than many of them thought a year or two ago. His own view was that although large changes in hinge moment characteristics did take place at high Mach numbers, nevertheless what work had been done did appear to indicate that something could be done to avoid these effects. Spring tabs had proved satisfactory in one case up to Mach numbers of at least 0.8, but he would not like to be dogmatic about their use until more experience had been gained.

He was glad that Mr. Edwards had drawn attention so forcibly to the fact that nearly all the flight research discussed in the lecture had been made on aircraft which differed fundamentally from many of those which were now being designed. One reason for this was that it took a long time to build even a purely experimental aircraft, so that although the aircraft needed to perform a fairly complete plan of research on future types were initiated as soon as the requirements became reasonably clear, few of these aircraft had as yet become available for flight research. In the meantime, flight research at the R.A.E. had been directed mainly towards the understanding of the fundamental problems of high speed aerodynamics and the perfection of experimental technique, rather than the investigation of the overall qualities of existing aircraft, in the hope that most of the conclusions reached might be applicable to future types.

The determination of the point of an aeroplane at which shock waves might be occurring was difficult without comprehensive pressure distribution measurements involving prohibitive labour. An attempt was being made at the R.A.E. to develop a method of photographing shock waves in flight, but it was doubtful whether this method would ever be sufficiently adaptable to enable shock waves on nacelles, cockpit hoods, etc., to be explored in the way envisaged by Mr. Edwards. The value of wool tufts for examining the nature of the flow at high Mach numbers was discussed briefly in the lecture. It was possible that this method, which had been so useful at the other end of the speed range, might prove the best method of locating compressibility faults at high speeds, and a suitable technique was at present being developed at the R.A.E.

It was true that the snaking experienced on jet aircraft, such as the Me.262 and Meteor, had never been cured. Recent work in this country strongly suggested that the effect was caused primarily by variations in rudder hinge moment characteristics with speed, accentuated by low directional damping. It followed, therefore, that on future aircraft with power controls snaking should not occur, provided that backlash in the con-

trol circuits could be eliminated. On aircraft without power controls, the solution would depend on whether the rudder could be designed so that the variations in b_1 and b_2 with speed were negligible, or at any rate controllable.

Mr. Quill: He believed that the use of a liquid-fuel rocket to accelerate an aircraft in the supersonic region was suggested a number of years ago, and it undoubtedly had a number of advantages, but the practical difficulties of making liquid-fuel rockets work with safety were considerable.

Mr. Quill rightly stressed the importance of having plenty of power available in an experimental high speed aeroplane so that the speed range required could be obtained in level flight or even perhaps in a climb. He agreed most emphatically, not only because of the greater safety but also because the interpretation of the results obtained in level flight was so much simpler. It was interesting to contemplate the possibility of carrying the suggestion a stage farther, by exploring the trans-sonic region in a vertical climb, when the trim changes could be made zero.

Mr. Morgan: Mr. Morgan appeared to make the point that they got more from the pilot than the automatic observer. He would not entirely agree with this. There had been many occasions where a pilot had quite honestly got the wrong impression and the automatic observer had shown something quite different.

Mr. Morgan drew attention to the large number of factors affecting stability and control at high Mach numbers and the consequent difficulties in carrying out really systematic work in flight. This was an extremely important point, and he entirely agreed with the conclusion that they must rely mainly on model tests for systematic research. It followed that great importance should be attached to attempts to establish a correlation between model and flight tests.

Lieut. Comdr. Brown: He could not agree more with Lt. Cdr. Brown about the importance of liaison between the technical staff and the pilots and had to confess to being responsible for quite a number of silly things, including perhaps switches in which the pilot had to do a contortionist act before they could be operated. But he thought they had improved in that respect and he hoped they would continue to improve.

He was glad that Lt. Cdr. Brown gave such unqualified support to the piloted experimental aircraft, compared with the pilotless model. As he had said in the lecture, he had himself great faith in the future of piloted research in the trans-sonic region, but the difficulties and hazards of this work could not be denied. The work which had been done in the past by pilots at the R.A.E. and elsewhere, however, left them in no doubt that these future difficulties would be successfully met.

Mr. Bateman: Just as he agreed on the value of putting a pilot in, he found he agreed largely with what Mr. Bateman said about the free flying pilotless model. The important thing was that there were two techniques which had to be used. In this country, where resources were a little limited, they must make the maximum use of those two methods.

Mr. Richards: The most important point raised by Mr. Richards was the suggestion that the buffet barrier was not so important as they had made it out to be. To some extent he agreed with what Mr. Richards had said, in that the buffet barrier did not occur until drag rise had begun. The evidence suggested in fact that the drag had risen by 30 to 50 per cent. before the buffet began, but he thought that this did still imply a definite restriction on the maximum lift, even in the case of a long-range bomber; in the case of a fighter the importance of the buffet barrier was obvious and not open to dispute.

Mr. Jameson: As might be expected, the behaviour of an aircraft in a stall at high Mach number varied greatly from one aircraft to another, and also depended on the actual Mach number. At moderate Mach numbers, say up to about 0.6, there was often little warning of the stall, the nose dropping away smoothly when the maximum C_L was reached. At higher Mach numbers there was usually some degree of buffeting before the stall. In some cases this pre-stall buffeting was sufficient to prevent the stall itself being reached. There was still much to learn about the nature of the stall at high Mach number, before they could hope to anticipate the behaviour likely to occur in any particular design.

Mr. Lock: Mr. Lock had expressed some scepticism about the remarks made in the lecture regarding the origin of the drag rise. What he had said was that most of the drag rise, up to quite a high Mach number, was

associated with the loss in pressure through the shock wave. He did not mean to imply that if they could analyse completely the loss in momentum in the wake that they could not then deduce the drag from that.

With regard to stability changes relative to the drag rise, they certainly occurred before the drag rise, particularly variations in hinge moment characteristics which occurred at quite low Mach numbers. But the catastrophic changes in stability usually occurred after the drag rise had risen by from 30 to 50 per cent.

Mr. Young: His remarks on the effect of large values of $[\partial C_M/\partial C_L]_M$ were particularly interesting. It was possible that the inconsistency in the behaviour of some aircraft at high Mach number might be explained on similar lines.

He did not think the positive value of $[\partial C_M/\partial C_L]_M$ observed on Meteor and Vampire at low incidence and high Mach number could be due to local shock stalls at the nacelles or booms causing increased downwash at the tailplane. If this effect were appreciable it would be reflected in the variation in elevator angle to trim at constant C_L. Unfortunately, as he had emphasised in the lecture, it was difficult to obtain from flight tests an analysis of the contributions of variation in aerodynamic centre, $dC_L/d\alpha$, etc., to the overall stability characteristics.

Dr. Lachmann: The suggestion about having artificial feel as a function of Mach number was interesting, but he did not think much would be gained by such a device. At best it could only give the pilot a rough impression of the Mach number, whereas in fact it was necessary to know the Mach number quite accurately if trouble were to be avoided at very high speeds. A reliable Machmeter in a prominent position in the cockpit was the best safeguard. It should be mentioned, incidentally, that recent experience at the R.A.E. had suggested that controls with no artificial feedback of any kind—the stick force being independent of speed—might be quite acceptable in practice.

Mr. Perring: Regarding the importance of technique and particularly electronic technique, he could not agree more. He certainly thought that although a certain amount of development had taken place in technique there was still much to be done, particularly in electronic technique. An electronic method of measuring pressure distribution in flight for example, which was at present being developed at the R.A.E. was promising, and would, they hoped, do away with the enormous labour involved in present methods of measuring pressure distribution.

Mr. Perring drew attention to the large number of complex factors which affected stability characteristics at high Mach number, and asked if the overall stability could not be made acceptable by means of a mechanical automatic pilot which took care of all the factors. There were certainly attractive possibilities in this direction, but it would not be easy, because the automatic pilot would have to cope, not simply with unstable derivatives, but with derivatives which might be changing rapidly with speed. Moreover, it would be necessary to know in advance the way in which the derivatives varied with Mach number.

Mr. Perring also mentioned the small depth of the region of disturbed flow behind a shock wave observed in wind tunnel tests. This was an important point. The only full-scale evidence on the depth of the disturbance was in connection with the flow in wing-nacelle, wing - fuselage or fin - tailplane junctions. In these regions the depth could be quite large. The disturbance on the plain wing surface, however, had only been examined with surface tufts in flight. Some tests had therefore been started at the R.A.E. to investigate the depth of the disturbance.

In conclusion, he wished to emphasise the fact that research of this kind was very much the work of a team, and he wished particularly to acknowledge gratefully the work done by members of the high speed flight section at Farnborough, who had been responsible for practically all the experimental work he had discussed, and to the pilots who had carried out this work under conditions which were always difficult and often hazardous.

INFLUENCE OF RECENT CIVIL AIRWORTHINESS REQUIREMENTS ON AIRCRAFT DESIGN*

by

W. TYE, O.B.E., B.Sc., F.R.Ae.S.

1. INTRODUCTION.

In preparing this lecture I found it necessary, when considering recent changes in aircraft design, constantly to ask myself the question "Is this particular change due to airworthiness requirements or does it arise from reasons other than airworthiness?" In fact, one must consider whether requirements have any influence at all on the development of trends in design. Should design be likened to a runaway horse with requirements following some way behind, or are requirements a strict rein by which the pace and direction of design is controlled?

My own answer to these questions is that the pace at which development takes place is not influenced at all by airworthiness requirements, but that requirements help to prevent design from running off the path of safety. To carry the analogy a little farther, the faster the development is, the more difficult it is to keep it running on the path of safety.

The rapidity of development in the past few years has been great. The introduction of turbine engines and pressure cabins has made it possible to fly at speeds and height, double, if not more than double, the limits which have been practicable hitherto. Whereas, in the normal course of events it is possible to gain operational experience of one generation of aeroplanes before the next, slightly more advanced, generation appears, this is not now the case. We are being forced to extrapolate the operational experience gained on medium size, low speed, low altitude aeroplanes, in order to apply it to very large, fast, high altitude aeroplanes. In this respect the difficulties of keeping airworthiness requirements abreast with development is extremely difficult.

* A lecture given to the Graduates' and Students' Section on 14th April 1948.

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2. THE OBJECTIVE OF CIVIL AIRWORTHINESS REQUIREMENTS.

Before discussing the detailed influence of airworthiness requirements it is necessary to define more precisely the aim of these requirements. Expressed in general terms, the objective is to ensure that those accidents which are directly or indirectly attributable to the aeroplane itself are reduced to the practicable minimum.

Taking a long view, the aim is to outlaw accidents completely, but this is not, at present, a practical possibility. The reason is that nearly every safety measure has its cost. The direct effect is shown in the first cost of the aeroplane itself; the indirect, but usually much more important, cost is the reduction of payload which corresponds to the weight of the safety measure. Were all the facts and figures available, it would be possible to relate the cost of air travel to the degree of safety provided. One could then say, that by increasing the fares by x per cent., the overall measure of safety could be raised by y per cent. No scientific methods of making such an estimate are available, so that much depends on general engineering judgment based on the concensus of opinion of operators, constructors, users, insurers, and other aeronautical experts. Therefore, although the target of airworthiness requirements cannot be defined with scientific precision, the underlying intention is to reduce steadily accidents attributable to the aeroplane, at the same time avoiding economic consequences which would be so serious as to make air transport more of a luxury than it already is.

3. POINTERS TOWARDS THE ACHIEVEMENT OF THE OBJECT.

The preceding remarks lead to a principle which the requirement writer must always bear in mind. He should apply his efforts in directions which are likely to achieve the

greatest improvements in safety at the lowest possible cost.

Guidance has been derived from an examination of accident figures. The following Tables are suggestive. The percentages are given in terms of total number of accidents.

TABLE I.

U.S.A. Civil Airlines (Mean for years 1940, 1941, 1942)[1]		
Pilot error of judgment		39.5%
Aeroplane failure (including bad maintenance)		21.0%
This includes:—		
Landing gear ...	13%	
Flying qualities ...	1%	
Power plant	7%	

TABLE II.

Air Transport Auxiliary (Mean based on a total of 1961 accidents)[2]		
Pilot responsible		37%
This includes:—		
Cockpit drill ...	4.5%	
Swinging	5.0%	
Under and over-shooting	4.5%	
Collision on ground	6.5%	
Aeroplane failure		44%
Landing gear ...	11.5%	
Power plant ...	19.5%	
Miscellaneous ...	4.0%	
Maintenance ...	9.0%	

Although the tables differ in some respects, there are certain clear indications. Failure of the power plant stands out as a serious weakness. These failures are partly attributable to the engine itself and partly to the installation. Considerable attention, therefore, has been paid to the power plant requirements; the engine type test has been greatly increased in severity; and the requirements for fuel, oil, cooling and other power plant installations have also been considerably amplified. Many of the failures are attributable to defects which in themselves are minor and are corrected at low cost. It remains to be seen whether amplification of the requirements achieves the desired object. There is a strong opinion among some power plant experts that the real cure lies in intensive flying trials, in conditions as near to operational as possible, for a sufficient period to eliminate the main weaknesses.

Because of the doubts about power plant reliability, a second line of defence has been developed. This is to render the aeroplane as safe as possible in the event of engine failure by the introduction of performance requirements based on the assumption of engine failure. It is unfortunate, but at present inevitable, that power plant unreliability should lead to these flight performance limitations, as there is a likelihood that safety improvements obtained in this way will prove expensive.

Landing gear accidents, fortunately, are often not catastrophic. Some arise from structural failures and some from failure of the retracting mechanism. There has been considerable re-casting of the landing gear strength requirements and this has already shown signs of bearing fruitful results. Improvement in retraction mechanism probably rests mainly with designers, as failures are often of a detailed kind which are not likely to be affected by the amplification of requirements.

Now let us consider accidents attributed to the pilot's errors of judgment. I believe that accident investigation procedure can lead to misleading impressions. For instance, if a pilot mismanages the fuel cocks it is no doubt an error, but how much better if the design were such that mismanagement led to no disastrous results. While it is true that however simple the aeroplane is to manage, there will always remain a residue of pilot error accidents, I am convinced that the present high percentage of accidents attributed to the pilot could be substantially reduced by a major attack on the aeroplane design itself.

In the A.T.A. figures quoted, the accidents attributed to cockpit drill, swinging, under- and over-shooting, and collision on the ground, amounting in all to about 20 per cent. of the total accidents, are probably all amenable to improvement through the medium of aeroplane design. So far, insufficient attention has been paid to this problem and there is an opportunity for the requirements to lead design, once the problem has been fully analysed.

The necessity in designing aeroplanes for them to be made as safe as possible when a crash does occur, is made clear by a study of recent British reports on civil aeroplane accidents. An analysis of 20 reports

published by the Accident Investigation Branch, which refer to accidents between May 1946 and August 1947, shows the following: Of the 158 persons involved, nearly half were killed and one-third were injured. In the accidents in which the aeroplane flew into the ground (often in low visibility) one-third were killed. Where the aeroplanes made forced landings, over half were killed. This would indicate that even in the high speed crash (as compared with the low speed forced landings) the occupants can be saved by suitable protective measures. On five occasions only, fire broke out, but on these occasions three-quarters of the occupants were killed. Thus, fire still remains a serious risk.

4. EFFECT OF THE REQUIREMENTS ON DESIGN.

In the next sections of this lecture, I will deal with a number of examples of the way in which requirements introduced recently, some for the reasons mentioned above, are influencing design. In doing so it is important to separate the changes of design which are a consequence of aeroplane development itself, from those which arise from requirements. For instance, a post-war aeroplane flying at 300 m.p.h. is subjected to greater loads than the pre-war aeroplane flying at 150 m.p.h. Some of the increase of strength required is attributable to the increase of speed. Whether any increase is due to greater severity of the requirements themselves remains to be considered.

5. FLIGHT REQUIREMENTS.

5.1. FORM OF REQUIREMENTS.

Modern flight requirements have a strong influence on design.[3], [4], [5] Those governing performance tend to determine the power required (and hence number of engines); those governing control and stability affect the size and general arrangement of control and stabilising surfaces.

The performance requirements are of the following form:—

(*a*) Operating requirements which relate take-off and landing distances to the available runway lengths, and which stipulate the margins by which obstacles must be cleared, both in the vicinity of the aerodromes and *en route*.

(*b*) Airworthiness requirements which stipulate the characteristics which must be determined and scheduled in order that the operator can suit the aeroplane to the particular route.

(*c*) Airworthiness requirements which prescribe absolute minimum rates of climb, which would be limiting conditions if the aeroplane were operating from long obstruction-free runways and over flat terrain.

These requirements offer three broad ways in which to minimise the danger of engine failure:—

(*a*) to provide adequate performance with one engine failed wherever this may occur during take-off, *en route*, or approach,

(*b*) to limit stalling speed to 60 m.p.h. if the aeroplane has no engine-inoperative performance,

(*c*) to limit stalling speed to 70 m.p.h. if the aeroplane has the ability to stay up but not to take-off, with one engine failed.

5.2. EFFECT OF WING AND POWER LOADING.

A complete analysis of the effect of these requirements can only be made in relation to particular routes and runways. I am thus restricted to a few broad generalisations.

5.2.1. *Single-engined aeroplanes.*

The requirements rule out stalling speeds in excess of 60 m.p.h. and the resulting low wing loading will discourage the development of fast or large single-engined aeroplanes.

5.2.2. *Twin-engined aeroplanes.*

Because the twin-engined aeroplane has to operate on 50 per cent. power only when an engine fails, there is some discouragement to the twin-engined aeroplane. It seems likely, however, that the performance group which requires one-engine-inoperative-performance *en route* associated with a stalling speed limit of 70 m.p.h., will fit the small feeder line aircraft. One can visualise the pre-war twin-engined aeroplane, but with a little more power, as a class which will fill this role. There will then be a jump to twin-engined aeroplanes which are so fast that the power provided is adequate to make compliance with the full engine-inoperative requirements possible. Such aeroplanes will have considerably higher power/weight ratios than most pre-war civil types.

5.2.3. *Four-engined aeroplanes.*

For most high speed or large aeroplanes the absence of an absolute limit on stalling speed, provided that the aeroplane complies with

full engine-inoperative requirements, will be an inducement to design four-engined types, even in medium size aeroplanes. The power/weight ratio of current types of four-engined aeroplanes is unlikely to be materially altered by the performance requirements.

The effect of the engine-inoperative requirements on the choice of power loading and wing loading depends largely on the form of the climb requirements, about which there has been much discussion. I.C.A.O. standards stipulate that rate-of-climb should increase as the square of the stalling speed. To avoid the penalty of providing power for very high rates of climb the designer is driven to restricting stalling speed. The effect of this on flap design is described later. It is believed, however, that the present form of requirement is irrational. Studies recently made, in preparation for discussion at Montreal this year, seem to show that rate-of-climb should vary directly as stalling speed (not the square of stalling speed). If this proves to be the case the tendency to limit stalling speed will not apply so seriously.

5.3. Effect on flap design.

The need for high speed and economic structural design has led to steady increases of wing loading. Increase of wing loading tends to increase the speed at which a safe take-off can be made and this in turn tends to increase the take-off distance. There are two remedies available to prevent increase of take-off distance, to increase the power/weight ratio, or to improve flap design. For a given flap design, the take-off distance with all engines operating can be written very roughly as:—

L yards = constant × wing loading, lb. per sq. ft. × power loading, lb. per b.h.p.

$= cw\lambda$.

Before the war $w\lambda$ was commonly 250 to 400; now it is 500 to 800, thus tending to double the pre-war take-off distance. Since there is a limit to the expenditure on increasing runway lengths, and since it is uneconomical to increase power to balance the increases in wing loading, the designer is driven to seek improvements in flap design.

In this country flaps appear to have been viewed mainly as an aid to reducing landing speed, but there is every indication that in the U.S.A. the flap is being employed to reduce take-off distance. An analysis of the take-off distance of some modern American and British aeroplanes gives average values of the above simple formula as follows:—

American $L = 2.6w\lambda$

British $L = 3.2w\lambda$.

In other words, the British aeroplane requires 20 per cent. more runway length than the comparable American aeroplane. Even if there is a little optimism in the American figures—and my experience is that aeronautical optimism is not confined to the U.S.A.—the figure of 20 per cent. provides food for thought.

The influence on design has been to encourage flaps which, at take-off settings, provide increased lift with little increase of drag. Many modern aeroplanes employ large Fowler and slotted flaps, while the British designer has been more reluctant to give up the simple split flap. The more complex flaps probably weigh a little more, but if the take-off distance is substantially reduced, the price paid will be small for the advantage gained.

As previously mentioned, many present I.C.A.O. rate-of-climb requirements vary as stalling speed squared. There is thus a further incentive to employ, in aeroplanes with high wing loading, highly efficient flaps to reduce stalling speeds as far as possible. Such flaps also serve to reduce landing distances. The general effect is shown by comparing average flap areas of British and American aeroplanes, the latter having been designed with the I.C.A.O. requirements more prominently in mind.

	Flap areas $\frac{S_F}{S}$
American	17%
British	10%

where, S_F is total flap area, S is wing area.

5.4. Effect on fin and rudder design.

The necessity to provide for engine failure during take-off emphasises the need for first class directional control in flight at low speeds. If such control is not provided the minimum safe flight speeds, and consequently take-off distances, are increased. The first effect is an increase of area of the fin and rudder. Comparison of several aeroplanes designed before and after the introduction of I.C.A.O. Standards shows the trend clearly. Average values are:—

	Fin and Rudder area $\frac{S''}{S}$	$\frac{S''l}{Sb}$
Before I.C.A.O. ...	11%	0.050
After I.C.A.O. ...	16%	0.065

where
S'' = fin and rudder area
S = wing area
l = tail arm
b = span.

	Tailplane and elevator areas $\frac{S'}{S}$	$\frac{S'l}{Sc}$
Before I.C.A.O. ...	21%	0.70
After I.C.A.O. ...	26%	1.03

where
S' = tailplane and elevator area
S = wing area
l = tail arm
c = wing chord.

The net increase of fin and rudder area (taking due account of tail arm) is thus 30 per cent. Again, comparison of British and American aeroplanes is striking. Comparable American aeroplanes have fin and rudder areas about 30 per cent. larger than British aeroplanes. One is driven to the unpalatable conclusion that the U.S.A. has faced up to the design changes made necessary by engine-inoperative requirements more quickly than we have. If this conclusion is correct, the net effect again will be that British aeroplanes will require excessive runway lengths in comparison with American aeroplanes.

The use of large fins and rudders brings other problems into prominence. For example, to apply sufficient rudder angle, without excessive effort from the pilot, leads to spring tabs or other forms of assistor even for moderate sizes of aeroplanes. The fact that a large amount of rudder power is available makes it possible to apply large angles of yaw, and this in turn makes fin stalling a potential danger.

5.5. Longitudinal Stability Requirements.

Present civil requirements for longitudinal stability demand positive stick-free static stability. They also require that the static margin, stick-free, must not exceed the static margin, stick-fixed, by more than 0.05. This means, in effect, that a slight degree of stick-fixed instability is accepted, but that the difference in stability stick-fixed and stick-free is limited.

Time does not permit a detailed analysis on the effect of control surface design, but a general indication of the effect of these requirements on the overall size of the tailplane and elevator is given below.

A comparison of several aeroplanes shows the following average results:—

The net increase in tail area, making allowance for the tail arm, is of the order of 50 per cent. If I may once again draw attention to the Anglo-American scene, comparison of similar types shows that U.S. aeroplanes have tailplane areas about 35 per cent. greater than British aeroplanes. It is true, of course that the tail area (or tail volume) is not the sole criterion of stability; to be exact, other characteristics should be taken into account. The overall impression remains, however, that the U.S.A. is a step ahead in meeting the recent efforts to improve stability.

5.6. Other Effects of Flight Requirements.

In the requirements for engine-inoperative take-off it is assumed that the pilot will have to concentrate on handling the main controls and that there will be no opportunity to feather the propeller immediately. Since the performance is subject to great improvement if the inoperative propeller is feathered, there is a considerable incentive offered to automatic feathering devices. One modern American aeroplane is flying with such a device.

In these same engine-inoperative requirements retraction of the landing gear is assumed to be initiated at the start of climb away from the runway. Thus, if the retraction is completed quickly, both the take-off distance to 50 feet and the ensuing climb are improved. The advantage in performance is offset by the increased weight of the retracting motors but, within limits, a net gain seems likely to be achievable by speeding up retraction times.

5.7. General Note on Flight Requirements.

The inter-linking of airworthiness and operating requirements makes it absolutely essential for the aeroplane designer to have

a full knowledge of the routes and runways on which the proposed aeroplane will operate. Otherwise the aeroplane is almost certain to be uneconomical in relation to the route. It remains to be seen whether the highest overall economy results from high wing loading and enormous runways, or more moderate wing loading and reasonable runways. Except for very special duties (*e.g.* trans-Atlantic flights) the latter appears to be the more likely to prove the best compromise.

6. STRUCTURAL STRENGTH REQUIREMENTS.

6.1. Effect of principal flight cases.

The flight cases principally effective in determining the structural strength are the symmetrical manœuvre cases and the gust cases. There have been substantial changes in both magnitude and method of expression of the requirements. Concurrently there have been big changes in design, *e.g.* speed and weight increases.

There is not time to describe the detailed changes of the requirements themselves, but to obtain a general impression of the effect on design, it is useful to compare the overall loads derived from pre-war and modern requirements in two cases. For the illustration I have selected two hypothetical aeroplanes:—

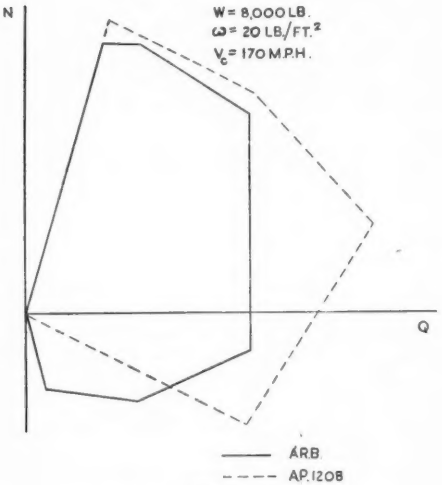

Fig. 1.
N-Q diagram for small aeroplane.

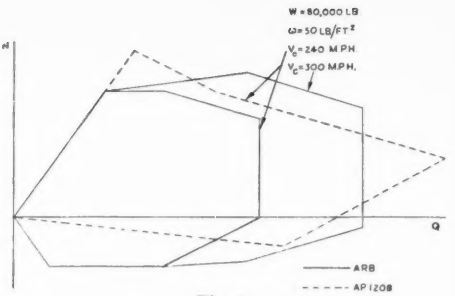

Fig. 2.
N-Q diagram for large aeroplane.

Aeroplane	A	B
Weight, lb.	8,000	80,000
Wing loading, lb./ft.²	20	50
Cruising speed, m.p.h. E.A.S.	170	240

The strength of the wing in bending and shear is mainly a function of N, the normal acceleration coefficient multiplied by the ultimate factor of safety. The strength of the wing in torsion is mainly dependent on Q, the value of $\frac{1}{2}\rho V^2$ multiplied by the ultimate factor of safety. Figs. 1 and 2 show N plotted against Q for the two aeroplanes, the envelopes being drawn through the manœuvring or the gust cases, whichever is the more severe.

The principal points to notice are:—

(*a*) the striking reductions in the maximum values of Q, partly consequent on the reduction of the diving speed allowed by modern rational requirements,

(*b*) the considerable reductions in positive values of N, consequent on reductions in modern requirements of both manœuvring and gust requirements,

(*c*) the increases in negative values of N at low values of Q, due to the introduction of a negative acceleration case at low speeds.

V-g records justify the reductions of (*a*) and (*b*). The increase of case (*c*) is primarily to cover the admittedly rare event of the transport aeroplane becoming inverted. (This event did occur recently.)

The conclusions reached above are contrary to the general impression that modern gust requirements are leading to very severe loading conditions. This apparent anomaly arises because I have selected for the purposes of illustration aeroplanes with moderate cruising speeds. As speeds increase

the gust requirements lead to rapid increase of loading. To illustrate this, if the hypothetical aeroplane of 80,000 lb. weight previously considered has a cruising speed of 300 m.p.h. E.A.S., the $N-Q$ diagram increases in size, as shown in Fig. 2.

The loads due to gusts are intensified by the effects of structural flexibility. Such effects are pronounced when the frequency of the wing in bending is low, so that in large aeroplanes flexibility effects are worse than in small aeroplanes. It may be that in very large aeroplanes the aerodynamic damping on the wings will counteract the increases due to flexibility. If this is proved to be the case aeroplanes between say, 75,000 lb. and 150,000 lb. weight will be most seriously affected. Present indications are that when flexibility and damping are taken into account the loads are likely in the worst cases to be of the order of 25 per cent. greater than the loads which would arise if the structure were rigid. Because of the increase of load with speed, and because of the increase due to flexibility, a great effort is being made to rationalise the gust requirements to the maximum extent, with a view to discarding any hidden margins.

The main design influence which these high gust loads are causing is the development of gust alleviators. A number of studies have been made and one or two practical alleviators are being developed. The principle on which the alleviators usually work is to employ a device which senses the on-coming gust and which sets in motion trailing edge flaps (which can be the ailerons themselves). The deflection of the flaps reduces the loads on the wings caused by the gust.

6.2. Effect of shock absorption and strength requirements on landing gears.

As previously mentioned, the landing gear has been the part of the structure most prone to failure. There has been a considerable effort to remedy this. The impression that present-day requirements for landing gears are more stringent in every respect than were the pre-war requirements, in some respects, is erroneous. A truer picture is that there has been a re-distribution of strength. It is first necessary to distinguish between changes which are the natural outcome of increases of landing speeds, and those which are associated with pure requirement changes.

6.2.1. *Shock absorption capacity.*

It is usually accepted that as landing speed increases, the vertical speed of descent at touch-down increases. The pre-war requirements assumed a rapid increase of speed of descent (and hence energy absorption) with increase of stalling speed. Modern requirements are more stringent at low stalling speeds but assume a much less rapid increase with stalling speed.

The following Table (see also Fig. 3) illustrates the point:—

Energy absorption in terms of airborne drop height

Stalling speed, m.p.h.	...	40	60	80	100
A.P. 1208	...	0.66	1.69	2.75	3.80
A.R.B.	...	1.0	1.15	1.50	1.90

Various factors which differ between A.P. 1208 and A.R.B. requirements make this comparison not quite true. Making reasonable allowances for these differences, they indicate that, very roughly, they cancel out, so the above Table is a reasonable indication of the comparative energy absorptions. At a stalling speed of about 45 m.p.h. the requirements are of equal severity. Above this speed modern cases are progressively less severe than pre-war ones, falling to 50 per cent. at a stalling speed of 100 m.p.h. The requirements themselves therefore are generally less onerous, and the increase of severity can be attributed to the natural consequences of increased landing speeds.

6.2.2. *Vertical loads.*

For the purpose of this paragraph and the two following ones, all loads are expressed in

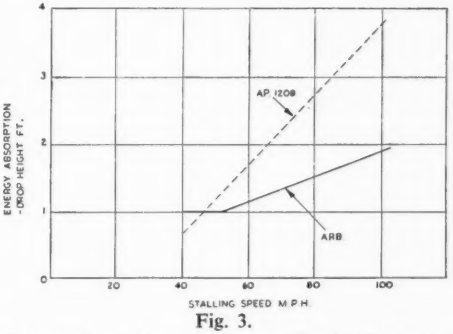

Fig. 3.
Energy absorption requirements for landing gear.

terms of the ultimate strength conditions, and the loads given on one wheel unit (assuming an orthodox arrangement with one main wheel unit on each side of the aeroplane) are in terms of the take-off weight W. The minimum vertical load in the landing cases prescribed in A.P. 1208 was $2W$. Present-day landing requirements take into account the actual reactions developed in absorbing energy and allow for differences between landing and take-off weight. Take-off cases have also been introduced but, in the case of large aeroplanes, the load is occasionally reduced because the large wheel is unlikely to sustain high loads in take-off and taxi-ing. Typical cases are shown below.

	Vertical load on main wheel unit	
A.P. 1208	$2W$	
A.R.B.	Small aeroplane	Large aeroplane
Landing	$2W$	$1.35W$
Take-off	$1.75W$	$1.6W$

There is little or no difference in the small aeroplanes, whereas large aeroplanes are subjected to less onerous loads now than previously.

6.2.3. *Drag Loads.*

A consequence of the higher landing speeds is to increase the loads which occur during the period of time that the wheels are spinning up in the touch-down. These increases of loading were noticeable during the war when drag load failures became a serious problem on some aircraft. A visual indication is given by the puff of smoke emitted by the tyres of the aeroplane as it touches down. Modern requirements therefore, impose relatively high drag loads in landing compared with earlier requirements. Take-off and taxi-ing requirements prescribe higher drag loads on small wheels compared with large wheels, as small wheels are more affected by rough ground. Typical values are:—

	Drag load on main wheel unit	
A.P. 1208	$0.5W$	
A.R.B.	Small aeroplanes	Large aeroplanes
Landing	$0.8W$	$1.05W$
Take-off	$0.8W$	$0.5\ W$

Recent research in the U.S.A. suggests that failure under drag loads has arisen from lack of shock absorbing action in the drag plane. If this proves to be the case a conceivable development is a re-arrangement of the shock absorbers to offer some freedom of movement in the drag plane, with possible consequential reductions in the drag loads. This appears to be a desirable development as it is likely that the weight of increased shock absorption would be less than that of the increases of strength.

6.2.4. *Side loads.*

Side load failures have also been a source of trouble, with consequential increases in the requirements. A new turning and swing case has been introduced to allow for the most common form of failure. Approximately, A.R.B. requirements lead to minimum inward acting side loads of $0.45W$ to $0.67W$, depending on the likelihood of swinging, and minimum outward acting loads of about $0.40W$. These compare with the A.P. 1208 loads of $0.35W$. With the introduction of aeroplanes which are not prone to swing, the increase of strength will not be too serious a hardship. Encouragement is thus offered to nose wheel arrangements.

6.2.5. *Overall effect on landing gear design.*

The overall effect of the several changes in landing gear requirements is:—

(*a*) in the case of typical large aeroplanes with high landing speed, to reduce substantially the energy absorption (below that which pre-war requirements prescribe), to reduce by about 20 per cent. the vertical loads, to increase the drag loads by as much as 110 per cent. and the side loads by 30 per cent. to 90 per cent.

(*b*) in the case of typical small aeroplanes with low landing speeds to leave practically unaltered the energy absorption, to leave unaltered the vertical loads, to increase drag loads by 60 per cent. and to increase side loads by 30 per cent. to 90 per cent.

7. DE-ICING REQUIREMENTS.

Present de-icing requirements for wings and tailplanes differentiate between the provisions necessary for mild icing conditions and severe icing conditions. For the former, fluid systems as we now know them and mechanical pulsating systems appear satisfactory. For the latter, high standards of thermal de-icing or liquid de-icing in which

the rate of flow is much greater than in previous practice, becomes necessary.

The provision of high rates of flow on aeroplanes which are likely to encounter severe ice for long periods is a severe penalty for fluid systems. I should, therefore, expect to see a trend towards thermal systems for such aeroplanes. For short range aeroplanes, or for aeroplanes which do not operate in parts of the world where severe ice is encountered, it seems that fluid systems will continue, at least until such time as thermal systems are more fully developed.

It is important, whether an aeroplane is intended for flight in icing conditions or not, that in the event of inadvertently entering such conditions the aeroplane should not become uncontrollable. Apart from obvious steps such as designing to avoid jamming of the control surfaces by ice in the gaps, the main danger arises from elevator overbalance. If the control is closely balanced to keep the hand loads small, or for other reasons, a small accumulation of ice on the tailplane can make control very difficult. Present evidence suggests that it is important that b_2 (the coefficient linking hinge moment with elevator angle) should not be too low. The net effect of this will be to encourage power operation of elevators, in order that b_2 can be kept reasonably high.

8. "CRASHWORTHINESS" REQUIREMENTS.

The previously quoted accident figures suggest strongly that more attention should be paid to safeguarding the occupants in a crash. In the 20 accidents mentioned, nearly half the persons involved were killed and one-third injured. Surely, it is possible to reduce these numbers?

Safety belts.

It has frequently been demonstrated that, provided the passenger is restrained in his seat and is not thrown against sharp or hard objects, he can sustain the extremely high accelerations occurring in some crashes. The pre-war lap strap, which provided little safety when thrown forward in a crash, has been prohibited; the safety belt fitting into the wearer's groin has taken its place. This is designed to withstand 6g forward, with very little increase of weight in the strap or seat structure. I believe a further increase to 12g or 15g could save many lives and would not cause serious design penalty. Alternatively, a backward facing seat with a head rest offers ideal protection.

Emergency exits.

Pre-war requirements demanded one exit for every three occupants. To avoid the large aeroplane becoming a cullender, this has been reduced to about one exit per seven occupants. The minimum size permitted, 19 in. by 26 in., is, in my opinion, too small. The present requirements, however, permit a reduction in the numbers of exits provided that they are larger, and this I believe is a safer method. The requirements stipulate that the exits should not jam in a crash and that the method of opening should be simple, rapid and obvious. In two recent crashes, the exits caused trouble and more effort in meeting these requirements is necessary.

Fire.

Great progress has been made during the war years in providing against fire in the air. The effect on design is seen in the provision of fire extinguishers in the engine bay, the careful use of bulkheads and cowls, the provision of fuel cocks, the use of fire resistant pipe lines and so on. The problem of the crash fire is still with us. In British aeroplanes crash switches, which automatically discharge the fire extinguishers, are fitted. The present designs are not wholly reliable and improvements are being sought. Effort should also be directed towards prevention of fire by reason of the layout and design of the systems containing inflammable fluid. In a lecture by Glendinning and Drinkwater[6] a number of practical suggestions were made and these are worthy of the most careful consideration.

9. CONCLUDING REMARKS.

I have discussed at some length the influence of requirements on design. In a few years' time it will be possible to show whether the increased standards of safety have borne fruit in reducing accident rates. At present the most one can do is to show the overall reduction in accident rates over the past few years. Although these accidents are attributable to several causes, the designer can claim some credit for his contribution towards the general improvement. The following figures are drawn from several sources.[7], [8], [9]

Passenger fatalities per 100 million passenger miles

Period	British Airlines	U.S.A. Airlines
1926-30	54	—
1931-35	35	9
1936-40	16	5
1941-45	10	2.5
1946	8	1.5
1947	11*	2.5†

Transport Command scheduled services (1945-46) 2.5

* 18 months ending 1st January.
† First 11 months of 1947.

The downward trend, particularly from 1926 to 1940 is notable (see Fig. 4). Lest I should close on too complacent a note, I suggest our first target should be to achieve the American rate, which has been consistently four times better than the British. Our second target should be to equal the railways which are of the order of 50 times better than British airlines.

I am indebted to the Air Registration Board for permission to read this lecture. The opinions expressed are my own.

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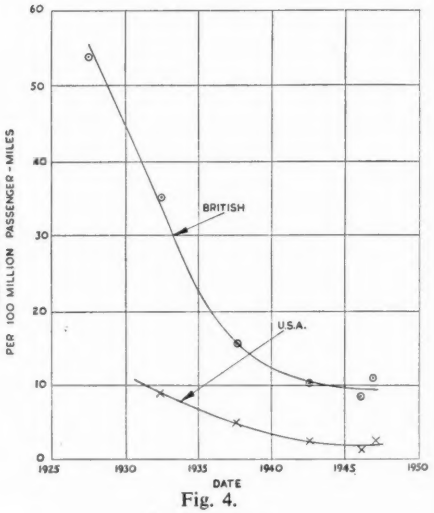

Fig. 4.
Accident rates.

MAINTENANCE DESIGN QUESTIONS

by

Lieut. (A) (A/E) T. E. G. BOWDEN, R.N., A.F.R.Ae.S.

INTRODUCTION.

From the correspondence columns of the JOURNAL it is obvious that there is a great deal of interest in the present-day standard of maintenance design and that the general consensus of opinion is that it is not up to a high enough standard.

In order to stimulate still further the interest in design for maintenance the following series of questions are asked. These questions are the thoughts that run through the mind of a maintenance engineer when he is introduced to a new item of equipment. The perfect maintenance design is extremely rare, *i.e.* when all the questions can be answered in a satisfactory manner.

It is easy to produce what seems to be an efficient design on paper but the conditions of a well-lit and well-heated drawing office are different from an unheated hangar early in the morning of a winter day.

The importance of maintenance being considered right through all the design stages is even more vital these days, when the number of aircraft being manufactured is less than during the war years and the economic side is just as important as the performance figures. In fact, the words "economy" and "maintenance" are bound together. It is not possible to issue modifications in order to correct faulty maintenance design and still keep a high percentage of aircraft flying.

The questions are not meant to be a final and exhaustive list but rather more to promote interest among the design side of the Industry and to bring home the difficulties of maintenance.

Practical examples showing where improvements can be made and giving a new viewpoint, perhaps, of maintenance problems to design staffs, are given with the questions.

QUESTIONS.

1. *Can the item be replaced, if damaged or requiring servicing, without having to remove any other item of equipment?*

On an aeroplane which is in common use to-day, the hydraulic flow-control valve has to be removed because the internal valve seatings are unserviceable, thus causing the flaps to droop. Before this can be done it is found that the guns have to be removed in order to make the bolts securing the flow-control valve accessible. A job that should be completed in a couple of hours drags out to almost a couple of days.

This difficulty should have been noticed in the design stage, but the hydraulic and armament sections worked separately and probably no one considered the two together.

2. *Are there any special threads, hexagons and so on, which will mean the manufacture and supply of special tools for the adjustment or removal of the item?*

Special tools may be required for major structural removals but they should never be needed for normal day-to-day maintenance.

An example of this difficulty is an aeroplane with a drain plug in the coolant radiator with a hollow, square-headed plug of unusual dimensions. It has been found that the detachable handle used for winding the hangar lights up and down fits nicely, as the square operating end is a perfect fit in the plug. In this way the difficulty was overcome but, it should never have occurred.

3. *Are there any access panels to the item? If so, are they large enough to enable an average hand and arm to be inserted, complete with spanner or screwdriver, to make the removal or adjustment?*

Access panels are usually too small, probably because of structural design difficulties, doubling the time needed for small replacement jobs. As an example, an aircraft has an access panel four inches in diameter and two feet away from the air-charging connection in the tail wheel oleo. To fit the charging adaptor requires more luck than skill because it means inserting an arm, bending the elbow and working blind, trying to

screw the adaptor from the pump on to the oleo. Even when located, the tightening of the screw is a problem and the time taken for the job is usually an hour. Another point is that the access panel is held on by a large number of small screws.

Another trouble with access panels is the fact that some may have to be taken off or opened while the aircraft engines are running, for example, starter trolley plug-in points. In some cases the slipstream makes it extremely difficult to replace the panel and frequently the panel is damaged and eventually not fitted.

4. *Are the bolts or screws attaching the item to the structure peaned over, making it difficult to remove without damage to the structure*?

If this occurs it is probably because the particular item is not expected to need replacing. Nevertheless some items of equipment attached to the structure by peaned-over bolts often have to be replaced in service. The pilot's de-icing hand pump on one aircraft would appear to be easily removable at first sight. On closer examination four 2BA bolts are found, carefully peaned-over, attaching the pump to the structure. To complicate matters, there is some electric wiring adjacent to the fitting which prevents the use of a file, unless great care is taken to avoid damage. Consequently, a whole day can be spent replacing one unserviceable de-icing pump.

5. *What happens if the tool used to remove or adjust the item is dropped; where will it go and can it be recovered*?

This old problem is worse in these days of semi-monocoque fuselages. Often it is almost impossible to retrieve nuts, bolts, spanners and other similar things which may be dropped while a component is being replaced. Many examples of this problem have been given at various times but there are probably many others which may have caused accidents and have never been revealed because of lack of evidence.

6. *If the item is one which requires topping-up with a liquid, is it possible to position a good-sized can and pour the fluid into the item, or is it necessary to arrange a piece of tubing around several other items*? *What happens if some fluid is spilt and where does it go*?

This question is intended to cover the many cases of inaccessible header tanks, de-icing tanks, and others. When two men are required to top up a tank by means of rubber tubing and other devices, obviously little thought has been given to the problem of general servicing. In addition, this procedure is often wasteful. I have known a hydraulic header tank use up twice the amount of fluid theoretically required for topping-up purposes because the awkwardness of the position of the tank caused a considerable amount to be spilt. Another point in this particular case is that the spilt fluid flows over the oxygen pipe lines, with consequent risk of explosion.

7. *Should the item be damaged, can it be repaired with the aid of the contents of a normal tool box and normal supplies of material, or are special drills and unusual gauges of material required*?

This question really covers minor damage to small components and reminds design staffs that usually only the common sizes of drills are available. Also, if the number of different gauges of material can be reduced to a minimum, the problem of holding large stocks is reduced. It is understood that the larger components will probably have to be replaced as their repair would be beyond the capacity of the normal servicing unit.

8. *If it is assumed in the design stages that the item is likely to be damaged in normal service, is the spare part provided going to pick up with the existing attachment points or will it be necessary to elongate holes because the dimensional limits are not sufficiently good to ensure full interchangeability*?

This crops up frequently. The number of elongated holes, or drilled holes practically touching one another, would horrify the stress office if they were to examine an aeroplane which had been in use for some time.

9. *If the item is one which requires adjustment at frequent intervals can the work be done in difficult weather, i.e. are the adjusting screws, or alternatives, large enough to be turned by cold or gloved hands*?

Time and again items of equipment which require adjustment, or are supposed to be easy to remove, are extremely difficult. This is often caused by the existence of small

wing nuts, fasteners, or screws with slots that wear quickly and make handling with gloves or screwdrivers extremely difficult under certain conditions.

10. *Are adequate instructions issued, either in the aircraft publications or on the aircraft itself, in the form of labels giving ALL the necessary information for adjustment or removal*?

Although the majority of handbooks prepared by the design firms are full of information, it is felt that the description of some of the more common operations could be improved, with bigger diagrams, the more pictorial the better. I know of one example in a handbook which talks about topping-up with air to 302 pounds per square inch and 0.05 pints of fluid. Whoever prepared the figures can have had no practical experience in the maintenance of aircraft. If the particular items required those exact figures then it was not good maintenance design in the first place.

Wherever possible the information about pressures, methods of refilling and so on, should be on the aircraft in reasonably-sized letters, or on labels which will not get knocked off accidentally or get soaked in oil and become unreadable.

CONCLUSION.

These questions and comments are not meant to be exhaustive, but are intended more to stimulate interest and possible comment from both designers and engineers. The more these questions are discussed the more probable are the prospects of aircraft being designed equally for performance and maintenance.

I have quoted practical examples for each query so that there is something definite to work on in each case. No doubt all the examples could be multiplied many times.

Another point worth mentioning is that aggravating question about the identification of parts. The majority of aircraft parts are extremely difficult to identify as their part numbers are usually stamped on in ridiculously small letters and figures. If the size of the lettering could be increased wherever possible, so that a magnifying glass is not required, identification problems would be reduced.

Finally, if these ten questions and the comments on examples of faulty maintenance design have created any interest among design personnel this short paper will have served its purpose.

(*Correspondence on these questions will be welcomed.*—EDITOR.)

REVIEWS

Air Power in War. Lord Tedder. Hodder and Stoughton, London, 1948. 124 pp. 9 diagrams. 9s. 6d. net.

This is a reprint of the Lees Knowles Lectures delivered at Cambridge University in 1947 by the author.

Following the delivery of these lectures it was reported that Lord Tedder believed—nay, had stated—that a war could be won by air power alone. This is an important book and by reason of its importance it is necessary that the exact wording of the author should be given on this point:—

"Here, for what they are worth, are my own beliefs based on what I have seen and learnt during the war. I am utterly convinced that the outstanding and vital lesson of this last war is that air power is the dominant factor in this modern world and that, though the methods of exercising it will change, it will remain the dominant factor so long as power determines the fate of nations. I believe that sea power is still vital to our very existence, and I am sure that sea power, properly exercised, can still be one of the keys to our security and not merely a commitment. I also believe that, in view of the inevitable dominance of air power, purely passive defence would be certain and painful suicide; . . . properly understood and used, I believe it can be the guardian of peace until that happy day when nations realise finally that wars don't pay."

Nothing here to bolster up any idea that air power alone can win a war. That it can dominate the course of a war, however, is shown clearly and in incisive language by the author of these lectures, of which there were four: The Unities of War, Air Superiority, Air Power in Relation to Sea Power, and The Exercise of Air Power.

They are all lectures of supreme interest and of outstanding significance, written with a conciseness which can be commended as an example to authors of far less calibre. There is so much to be learnt from experience and all those who have the future safety of this country at heart would do well to study the conclusions of one who had such a wide experience of air warfare.

This is the kind of book from which, if one began quoting, it might not be easy to stop, for it is so full of just those things one wanted to know.

The reviewer, with a considerable restraint, gives only the quotation at the beginning of the review, and one at the end, and says emphatically in between that this is one of those books that those who make their living out of aviation should have in their possession.

The last quotation is:—"On 30th May 1945 Speer reported to Hitler that 'with the attacks on the hydrogenation plants, systematic bombing raids on economic targets have started at the most dangerous point. The only hope is that the enemy, too, has got an air staff. Only if it had as little comprehension of economic targets as ours would there be some hope that after a few attacks on this decisive economic target it would turn its attentions elsewhere'."

How glad our air staff must have been to know that the Germans, *too*, had an air staff!

British Standards Yearbook, 1947. British Standards Institution, London, 1948. 324 pp. 3s. 6d. net.

There are some 1,400 British Standards now current, ranging from Sand lime (calcium silicate) Bricks to Methods for the Chemical analysis of cheese. These are listed in order of number and also in a most useful subject index.

It is really remarkable how British Standards rush in where less bold Institutions would fear to tread. B.S. 1345 is a specification on women's blouses. I quote verbatim "This specification gives size designations and minimum dimensions for women's blouses made of woven cotton, linen, silk, rayon, wool or mixtures of any of these materials. The range covered is intended to fit wearers having bust measurements of 32 in. to 46 in. inclusive."

Some fifty different industries are represented on the Committee of the B.S.I. The Yearbook includes lists of members of these Committees as well as those of the General Council and the Divisional Councils.

It is only by means of this Yearbook that one discovers the wide and interesting and useful activities of one of the most remarkable Institutions in the world. One is tempted to buy some specifications purely by their intriguing titles, but it is most certain that some of the publications of the B.S. should be in every engineer's office. For example, B.S. 560 Engineering Symbols and Abbreviations. It deals with those symbols and abbreviations recommended for use in text books and technical papers.

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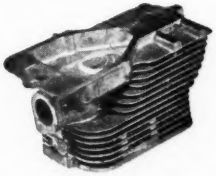

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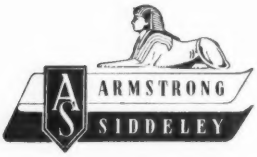

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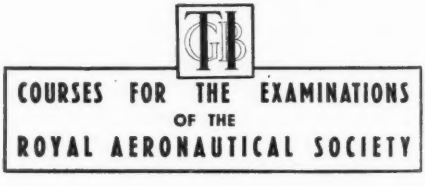

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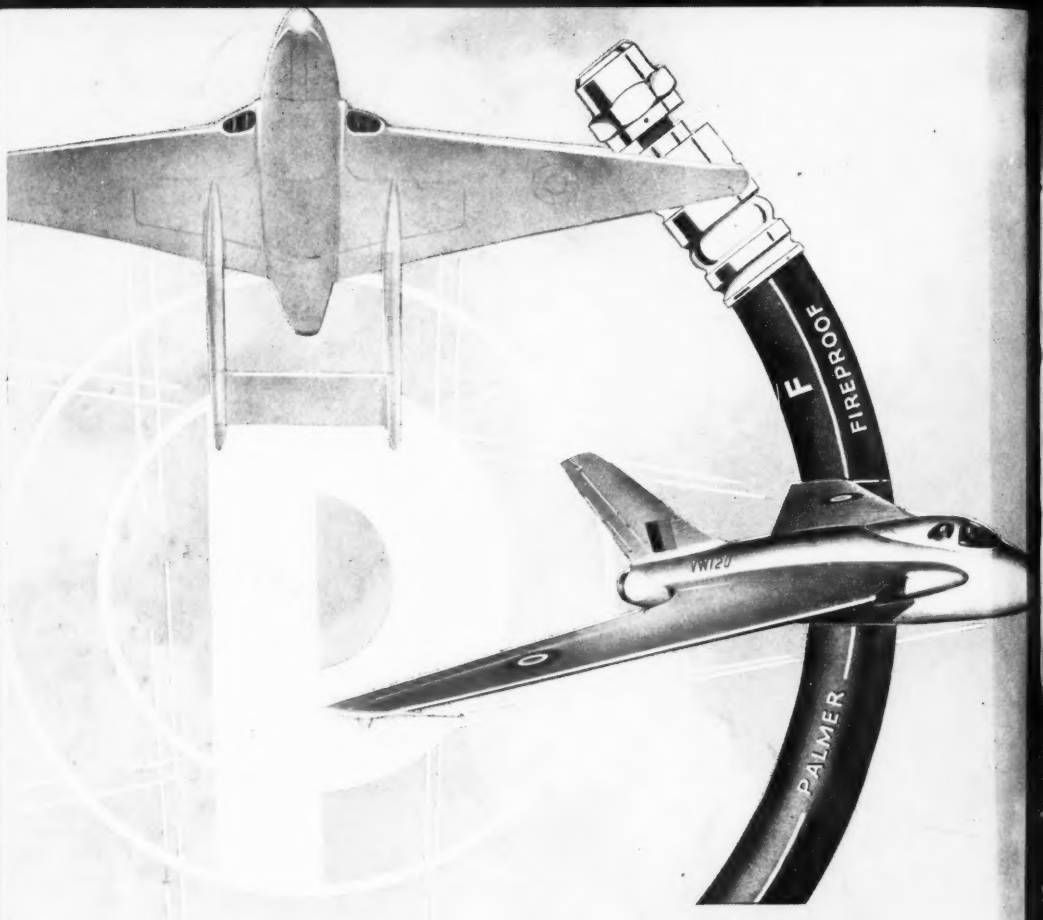

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